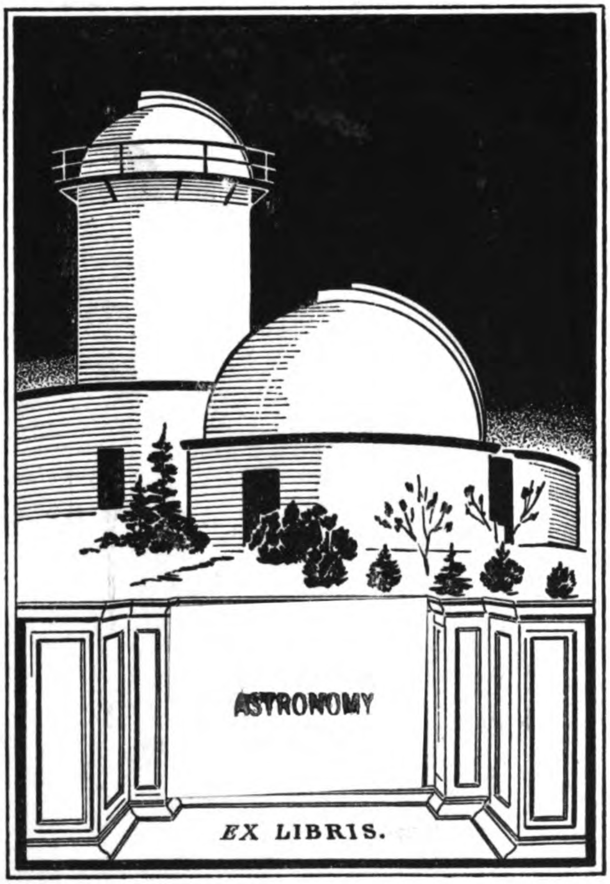
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TERRESTRIAL MAGNETISM
AND
ATMOSPHERIC ELECTRICITY

AN INTERNATIONAL QUARTERLY JOURNAL

VOLUME XXVII
MARCH—DECEMBER, 1922

THE JOHNS HOPKINS PRESS
BALTIMORE, MARYLAND
1922

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TERRESTRIAL MAGNETISM AND ATMOSPHERIC ELECTRICITY

An International Quarterly Journal

March-June, 1922

Conducted by

LOUIS A. BAUER
With the Co-operation of Eminent Investigators.

CONTENTS

PUBLISHED FOR
THE JOHNS HOPKINS PRESS, BALTIMORE
THE ABINGDON PRESS, 420 PLUM ST., CINCINNATI, O.
THREE DOLLARS AND FIFTY CENTS A YEAR SINGLE NUMBERS, ONE DOLLAR
THIS DOUBLE NUMBER, TWO DOLLARS

WHELDON & WESLEY, Ltd., 28 Essex St., Strand, LONDON, W. C., 2
THE ABINGDON PRESS (Cash Subscription) 420 Plum St., CINCINNATI
MAYER & MÜLLER Prinz Louis-Ferdinand Str. BERLIN

Entered as second-class matter at the Post-office at Cincinnati

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I hold every man a debtor to his profession; from the which as men of course do seek to receive countenance and profit, so ought they of duty to endeavour themselves by way of amends to be a help and ornament thereunto.—*Francis Bacon.*

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Washington, D. C., July 1, 1921. JOURNAL OF TERRESTRIAL MAGNETISM AND ATMOSPHERIC ELECTRICITY.

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Beginning with Volume XXVI, July, 1921, of this Journal the subscription rates, on account of the advanced cost of printing, had to be increased to the following per annum:

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CAPTAIN ROALD AMUNDSEN'S VISIT TO THE "CARNEGIE"
AT WASHINGTON, JANUARY 16, 1922.

Terrestrial Magnetism
and
Atmospheric Electricity

VOLUME XXVII MARCH-JUNE, 1922 Nos. 1 and 2

SOME RESULTS OF RECENT EARTH-CURRENT OBSERVATIONS AND RELATIONS WITH SOLAR ACTIVITY, TERRESTRIAL MAGNETISM, AND ATMOSPHERIC ELECTRICITY.[1]

By LOUIS A. BAUER.

1. Renewed interest was aroused by the remarkable earth-current disturbances of May 14 to May 20, 1921, and, as will be recalled, there were also at the time brilliant displays of polar lights, severe magnetic storms, and manifestations of pronounced solar activity. These disturbances and accompanying phenomena occurred over the entire Earth. Northern lights were observed in lower northerly latitudes than usual, and southern lights were seen as far north in the Southern Hemisphere as Apia, Samoa—a very unusual occurrence. In certain respects the disturbances, during the period mentioned, were similar to those which occurred August 29 to September 4, 1859. In the latter case, northern lights were visible as low as 18° North, and the magnetic disturbances were of almost unexampled size and rapidity, the accompanying aurora being extraordinarily brilliant and potential differences of 700 to 800 volts are said to have been reached on telegraph lines for distances of 500 to 600 kilometers.

2. Since Oersted's discovery, somewhat over a century ago, of the deflection of a compass needle by an electric current, hypotheses have been repeatedly advanced that the Earth's magnetic field is caused by electric currents circulating in the crust. However, most of the earth-current observations up to the present time indicate that the constant part of the electric current along a parallel of latitude is chiefly towards the east, instead of towards the west, as would be necessary to account for the observed phenomena of the magnetic needle.

3. At the International Electric Congress, held at Paris in 1881, such interest was aroused in the subject that systematic

[1] Presented before the Philosophical Society of Washington, February 25, 1922.

investigation of earth-currents, especially as observed in telegraph lines, was undertaken in various countries. Thus material was furnished for Weinstein's well-known publication[2] in which data obtained on two telegraph lines (Berlin to Thorn, 262 kilometers, and Berlin to Dresden, 120 kilometers), for four complete years, namely, from 1884 to 1887, were successfully utilized.

4. Unfortunately, the interest then aroused has waned and, as far as known, there has been but one observatory in recent years where systematic earth-current observations have been made, namely, at the Observatorio del Ebro, Tortosa, Spain, where a very valuable series has been obtained from 1910-1920.[3] May renewed interest be aroused in this important subject at the forthcoming Rome meeting of the International Geodetic and Geophysical Union!

5. The Department of Terrestrial Magnetism is planning to install earth-current lines for systematic observations at its magnetic observatories. This year such lines are to be installed at the Department's observatory at Watheroo, Western Australia, and in the following year at the Huancayo Observatory, Peru. The Commonwealth of Western Australia, besides making three Crown Grants, aggregating 200 acres, for the site of the Watheroo Observatory, furthermore has granted use by the Carnegie Institution of Washington, for purposes of earth-current investigations, of two 10-mile strips of land, each 1 rod wide, one of them running astronomically north and south and the other, astronomically east and west; these two strips of land start from the observatory-site and terminate each in a 10-acre tract.

6. Various initial investigations have been in progress at the Department's laboratory.[4] To Mr. O. H. Gish, appointed January 1, 1922, Associate Physicist of the Department, has been assigned the continuation of these investigations. Furthermore, in order to take advantage of the previous experience gained in such work, and to ascertain the direction in which further study is desirable, a discussion of the available data, especially for the 11-year series at the Observatorio del Ebro, was undertaken by the writer. The chief results of this latter study are here presented.

[2] *Weinstein, B.*: Die Erdströme im Deutschen Reichstelegraphengebiet und ihr Zusammenhang mit den Erdmagnetischen Erscheinungen. Mit einen Atlas. Braunschweig, 1900.

[3] Unfortunately the series was interrupted on January 1, 1921, because of defective earth-plates; it is much hoped that the defects will soon be remedied and the series continued.

[4] See *Terr. Mag.*, vol. 23, 1918, pp. 73-91 for a preliminary report by Dr. S. J. Mauchly, entitled, "A Study of Pressure and Temperature Effects in Earth-Current Measurements." (See also the article by J. E. Burbank, "Earth-Currents, and a Proposed Method for their Investigation;" *Terr. Mag.*, vol. 10, 1905, pp. 23-49.)

Earth-current Observations at the Observatorio del Ebro, 1910-1920.

7. Earth-current measurements have been made at the Observatorio del Ebro since January, 1910, along two lines, called here *N'S'* and *W'E'*, respectively. For brevity, the observatory will hereafter be designated "Ebro" merely. The pertinent data for these lines are given in Table 1, from which it will be seen that

TABLE 1.—*Pertinent data respecting earth-current lines at the Ebro Observatory.*

	N'S'	W'E'	
	1910-1920	1910-1911 (Jan.)	1911 (Feb.)-1920
Direction of line (from true North)	25° 16′ W	112° 37′ W	114° 46′ W
Distance between terminal plates	1,280 meters	1,420 meters	1,415 meters
Difference in level of terminal plates	8.8 "	6.8 "	6.8 "

they are each somewhat over a kilometer long, the angle between them being 87° 21′ during the period from January, 1910, through January, 1911; a change was then made in the W'E' line so that the angle between the lines closely approached 90°, namely, 89° 30′. For details respecting the installations, methods of observation, photographic registration, and evaluation of the electrograms, reference will have to be made to the various observatory publications.[5] The earth-plates were connected by aerial lines.

The *geographic position* of the Ebro Observatory is 40° 49′ N, and 0° 31′ E; accordingly G. M. T. hours are within two minutes of local hours. The *altitude above sea-level* is 51 meters.

8. Starting with Father Ubach's formulæ,[6] we have reduced for the period investigated the earth-current results, as published in the observatory bulletins, so that they would apply to the astronomical directions. For the five-year period 1914-1918, there will be found in these valuable bulletins corresponding magnetic and earth-current data for the 5 so-called "international magnetically-calm days" per month. In general, the earth-currents were comparatively undisturbed on these magnetically-quiet days, though in a few instances, it was necessary to utilize also the data on days marked in the Observatory publications as

[5] *Cf.* Article by José Ubach, S. J., Boletin mensual del Observatorio del Ebro, Tortosa, vol. 1, No. 1., Jan., 1910, pp. 51-55, and Mémoires de l'Obs. de l'Ebre. No. 4, La Section Eléctrique, par J. García Mollá, S. J., 1910, pp. 95-119.

[6] *l. c.*, pp. 51-55.

"electrically-calm." These cases were in July, 1916, and February, 1918, for the $N'S'$ currents, and in June, 1915, and January, 1916, for the W'E' currents. Account was also taken of some obvious typographical errors.

9. If $N'S'$ and $W'E'$ represent, respectively, the currents corresponding to the measured potential-differences in millivolts per kilometer, along the directions given in Table 1, and NS and WE, the currents along the astronomical directions, then we have for the period 1911 (Feb.)-1920:

$$NS = 0.908\ N'S' - 0.427\ W'E' = -N \tag{1}$$
$$WE = 0.419\ N'S' + 0.904\ W'E' = -W \tag{2}$$
$$R = \sqrt{(NS)^2+(WE)^2} = \sqrt{(-N)^2+(-W)^2} \tag{3}$$
$$A = \tan^{-1}(WE)/(NS) = \tan^{-1}(-W)/(-N) \tag{4}$$

The values of the quantities computed from the published data, with the aid of these formulæ, are given in Tables 2, 3 and 4. *The directions of the rectangular components of the observed currents are found to be from N to S and W to E.*

10. To facilitate the investigation of the relations between electric and magnetic effects, the signs adopted in this paper are in accordance with the following conventions: Magnetic component (X), along a meridian, being taken positive towards true North, implies that electric component (W), perpendicular to X (hence, along parallel of latitude), shall be taken positive towards true West; magnetic component (Y), along a parallel of latitude, being taken positive towards true East implies that electric component (N), perpendicular to Y (hence, along a meridian), shall be positive towards true North. Accordingly, *minus values of N mean that the meridional component of the observed earth-current flows from north to south, and a minus value of W means that the latitudinal component of the observed earth-current flows from west to east.* The following additional symbols are used: D for magnetic declination; I for magnetic inclination; H for horizontal intensity; Z for vertical intensity (taken positive vertically downwards), and F for total intensity. The magnetic components are expressed in terms of $\gamma = 0.00001$ C. G. S., and the earth-current data in millivolts per kilometer, designated by $v/k = 0.001\ V/k$ (volts per km.). Tables 2-5 give the electric and magnetic data for the 5 years, 1914-1918.

TABLE 2.—*Mean data for the magnetic elements and for the earth currents at the Ebro Observatory for the magnetically-quiet days, 1914-1918.*

Earth-Current Data				Magnetic Data						
−N	−W	R	A	D	I	H	X	−Y	Z	F
v/k	v/k	v/k	°	° ′	° ′	γ	γ	γ	γ	γ
204.4	113.8	233.9	29.1 (E of S)	12 34.6W	57 45.6	23295	22737	5073	36935	43670

TABLE 3.—*Monthly and annual values of components of earth-current data at the Ebro Observatory for the magnetically-calm days, 1914-1918, in millivolts per kilometer.*

Month	−N, or Component N to S						−W, or Component W to E					
	1914	1915	1916	1917	1918	Mean	1914	1915	1916	1917	1918	Mean
	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k
Jan	522	239	103	162	28	211	264	133	71	96	37	120
Feb	493	273	313	124	113	263	254	148	173	78	67	144
Mar	525	311	274	234	117	292	264	161	146	121	69	152
Apr	491	356	293	283	203	325	252	179	151	140	104	165
May	482	264	454	295	239	347	239	171	219	134	120	177
Jun	525	78	471	365	354	358	248	144	225	169	165	190
Jul	549	299	313	443	406	402	269	137	152	204	188	190
Aug	48	449	11	37	4	110	44	215	24	27	10	64
Sep	12	11	− 2	− 2	− 5	3	27	31	25	19	12	23
Oct	0	102	− 5	− 1	− 4	18	32	80	25	26	16	36
Nov	5	196	− 7	− 4	38	46	26	121	24	25	35	46
Dec	137	62	16	37	136	78	84	55	32	41	81	59
Mean	316	220	186	164	136	204	167	131	106	90	75	114

Magnitude and Direction of Earth-Electric Components at Ebro.

11. From Table 2 it is seen that the average value for 1914-1918 of $(-N)$ was 204 (*i. e.*, current flowed from north to south), and of $(-W)$ 114 millivolts per km. (*i. e.*, current flowed from west to east). *Hence, the component of the Ebro earth currents towards true South was nearly twice (1.8 times) the component towards true East. The resultant horizontal component, R, was 234 millivolts per km., or 0.2 volt per km. The average direction (A) of the resultant was 29° east of true south, or we may say that approximately the resultant horizontal component, R, of the earth currents circulating in the Earth's crust at the Observatorio del Ebro, Tortosa, Spain, was from NNW to SSE.* It is of interest to observe in this connection that the bearing at Ebro of the Magnetic North Pole (assumed to be

approximately at 70° N, 97° W) is 24°. 5 west of true north, whereas, the bearing of the north end of the Earth's so-called magnetic axis is about 15° west of true north. Hence, ***the resultant hori-***

TABLE 4.—*Monthly and annual values of resultant horizontal potential-gradient of earth-currents at the Ebro Observatory for the magnetically-calm days, 1914-1918, in millivolts per kilometer, and true directions of resultant horizontal component.*

Month	Resultant Horizontal Component (R)						True Direction (A), East of South					
	1914	1915	1916	1917	1918	Mean	1914	1915	1916	1917	1918	Mean*
	v/k	v/k	v/k	v/k	v/k	v/k	°	°	°	°	°	°
Jan.	585	273	126	188	46	244	26.8	29.2	35.6	30.7	52.9	29.8
Feb.	554	310	358	146	132	300	27.3	28.5	28.9	32.0	30.8	28.7
Mar.	588	350	310	264	136	330	26.7	27.4	28.0	27.4	30.7	27.6
Apr.	552	398	330	316	228	365	27.2	26.7	27.2	26.3	27.2	26.9
May	538	315	504	324	268	390	26.4	33.0	25.7	24.5	26.5	27.0
Jun.	580	164	522	402	390	412	25.3	61.6	25.5	24.8	25.0	28.0
Jul.	611	329	348	488	447	445	26.1	24.6	25.9	24.8	24.9	25.3
Aug.	65	498	26	46	11	129	42.5	25.6	64.5	36.0	67.0	25.3
Sep.	30	33	26	20	13	24	66.6	70.3	93.4	94.8	113.0	82.6
Oct.	32	130	25	26	16	46	90.5	38.2	101.1	92.1	102.8	62.6
Nov.	27	231	25	25	52	72	78.5	31.7	105.3	98.9	42.6	45.2
Dec.	161	83	36	55	159	99	31.6	41.4	64.3	48.4	30.8	37.1
Mean	360	260	220	192	158	238	Mean A (1914-1918) from Table 2.					29.1

* The values in this column are not the means of those for the separate years, but were derived independently from the mean values of the rectangular components for 1914-1918.

TABLE 5.—*Monthly and annual values of the magnetic components at the Ebro Observatory for the magnetically-quiet days, 1914-1918.*

Month	$X = 22700\gamma$ + tab. quantity						$-Y = 4900\gamma$ + tab. quantity						$Z = 36900\gamma$ + tab. quantity					
	1914	1915	1916	1917	1918	Mean	1914	1915	1916	1917	1918	Mean	1914	1915	1916	1917	1918	Mean
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
Jan.	−4	−8	02	41	56	17.4	300	279	209	136	81	201.0	85	44	35	59	−26	39.4
Feb.	05	−6	24	43	60	25.2	299	278	214	132	74	199.4	81	41	44	53	−25	38.8
Mar.	11	−9	36	58	57	30.6	292	269	196	129	69	191.0	84	32	71	27	−30	36.8
Apr.	12	−6	56	57	57	35.2	293	260	198	121	64	187.2	87	33	87	30	−23	42.8
May	15	08	66	65	73	45.4	288	256	190	118	58	182.0	89	40	90	17	−17	43.8
Jun.	22	10	72	68	86	51.6	292	257	177	113	55	178.8	90	50	97	11	−24	44.8
Jul.	26	09	70	64	81	50.0	285	257	180	102	53	175.4	96	68	102	20	−15	54.2
Aug.	26	12	65	53	69	45.0	278	238	180	98	43	167.4	89	39	83	16	−18	41.8
Sep.	16	09	46	64	73	41.6	271	212	152	102	34	154.2	83	29	52	14	−23	31.0
Oct.	10	06	39	59	71	37.0	272	206	139	92	30	147.8	70	33	40	−39	−34	14.0
Nov.	−1	−2	42	55	65	31.8	276	211	133	88	29	147.4	61	41	38	−29	−48	12.6
Dec.	−4	−3	45	49	59	29.2	277	208	136	83	22	145.2	53	40	62	−13	−54	17.6
Mean	11	02	47	56	67	36.7	285	244	175	110	51	173.0	81	41	67	14	−28	34.8

zontal component of the earth-currents at Ebro was approximately in the direction from the Magnetic North Pole towards south-southeast.

12. Since the direction of the $N'S'$ component of the Ebro current-measurements was from 25°.3 west of north to 25°.3 east of south (see Table 1), it happens that the published values of $N'S$ do not differ very much from our computed values (Table 4) of the resultant R, the direction of which on the average, for 1914-1918, as just stated, was from 29.1° west of north to 29.1° east of south. This also explains the comparatively small magnitudes of the published values of $W'E'$.

13. Weinstein's values of the constant part of the earth currents observed at Berlin in telegraph lines from 1884-1886 (July), given on page 15 of the publication cited in footnote 2, have usually been interpreted to imply that the resultant current was on the average approximately from NE to SW. There is, however, some question as to the precise interpretation of Weinstein's signs, and it is in fact possible to interpret them so that the resultant current would flow, as at Ebro, from the NW quadrant to the SE quadrant. Anyhow, if the first interpretation as given is correct, then the resultant current for the later period, beginning August, 1886, was approximately from NNW to SSE, as at Ebro. Weinstein himself does not appear to attach much value to his tabulated quantities for the "constant" currents, but, instead, confines his discussion almost exclusively to the diurnal and annual variations of the observed earth-currents and to their relations with the magnetic variations. As at Ebro, the average constant component along the geographic meridian was, in general, larger than that along the parallel of latitude.

14. Before passing to the next topic, it may be of interest to obtain some idea of the approximate *earth-current density* at Ebro. Taking 0.2 volt per km. as the average horizontal potential-gradient of the resultant current, and making use of such data as are readily available regarding conductivity of the soil, it is found that the earth-current density at Ebro may be of the order 10^5 times that of the current density of the vertical conduction current (3×10^{-2} amperes per sq. km.) of atmospheric electricity, or about of the order of magnitude of some of the current densities obtained for the vertical electric currents resulting from line integrals of the magnetic force.[7]

15. Looking over the extreme values of the observed earth-

[7] BAUER, L. A.: On Vertical Electric Currents, etc., *Terr. Mag.*, vol. 25, p. 156.

currents at Ebro, 1910-1920, it would appear that during periods of excessive disturbance the magnitude of the horizontal potential-gradient of the resultant current may reach a value of about 0.8 volt, or more, per km.

Annual Variation of Earth Currents at Ebro.

16. From Tables 3 and 4 it will be noticed that in each year there is a remarkable change in the tabulated quantities between the summer and the fall months. Thus on the average for the 5 years we have:

Month	N	W	R	A
July	−402	−190	−445	25°.3 E of S
September	−3	−23	−24	82 .6
Change	−399	−167	−421	−57.3

Table 6 contains the preliminary data for the annual variation of the magnetic and electric components at Ebro, as derived from Tables 3, 4, and 5, approximate allowance having been made for secular change of the magnetic components and for the observed progressive change in the earth-current components during the sun-spot cycle; also, for comparison, the Berlin earth-current data are given.

17. According to the quantities at the bottom of Table 6, we find that on the average during the summer months (April to September), the magnetic component X, towards the North, is increased, i. e., dX is plus, and that the electric component W, towards the West, is decreased (or electric component towards the East is increased), i. e., dW is minus. In the winter months (October to March) the average dX is minus, whereas the average dW is plus. If the magnetic variations, dX, were the result of the electric variations, dW, then they should be of the same sign, instead of opposite sign as is the case.

Turning next to the average quantities, dY and dN, for summer and winter months, it is seen that these correspond in sign. If, however, dY were the magnetic effect of the electric variation dN, then a value of about $dN = 50$ millivolts per km. would produce a magnetic change, dY, of but 1γ. Since the variations, dW, are in general considerably smaller than the dN, it is, accordingly, perhaps not surprising that no corresponding effect is readily discernible in the dX.

TABLE 6.—***Preliminary mean values of the annual variations of the magnetic components and of the earth currents at the Ebro Observatory for the magnetically-quiet days, 1914–1918.***

(Mean values for 1914–1918: Magnetic components, $X = 22736.7\gamma$, $Y = -5073.0\gamma$, $Z = 36934.8\gamma$; earth-current components, in millivolts per kilometer, $N = -204.4$, $W = -113.8$. Meaning of signs: +, numerical increase of X and Z, and algebraic increase of Y, N, W, and R. For the sake of comparison, the last column has been added, giving the annual variation of the resultant current in arbitrary units, a, at Berlin, as based on the Weinstein data for 1884–1887.)

Month	Mag. Comp.	Elec. Comp.	Mag. Comp.	Elec. Comp.	Mag. Comp.	Res. El. Comp.	
						Ebro	Berlin
	dX	dW	dY	dN	dZ	dR	dR
	γ	v/k	γ	v/k	γ	v/k	a
Jan.	−11.6	+4	−0.3	+13	−6.6	−6	+101
Feb.	−5.1	−22	−3.8	−43	−5.1	−62	+42
Mar.	−1.1	−32	−0.4	−76	−5.1	−92	−40
Apr.	+2.1	−47	−1.6	−112	+2.9	−127	−75
May	+10.9	−60	−1.5	−137	+6.0	−152	−60
Jun.	**+15.7**	−75	−3.3	−152	+9.0	−174	−61
Jul.	+12.7	*−77*	*−4.9*	*−199*	**+20.4**	*−207*	*−84*
Aug.	+6.3	+47	−1.9	+89	+10.0	+109	−47
Sep.	+1.5	**+86**	+6.2	**+193**	+1.3	**+214**	−5
Oct.	−4.5	+72	**+7.6**	+174	*−13.7*	+192	+18
Nov.	−11.1	+59	+3.0	+143	−13.1	+166	+88
Dec.	*−15.0*	+45	+0.1	+108	−6.0	+139	**+121**
Mean (Apr.-Sep.)	+8.2	−21	−1.2	−53	+8.3	−56	−55
Mean (Oct.-Mar.)	−8.1	+21	+1.0	+52	−8.3	+56	+55
Range	30.7	163	12.5	392	34.1	421	205

The signs given the annual variation, dR, of the resultant horizontal potential-gradient of the earth current, both at Ebro and Berlin, have the following significance: A plus value means a decrease and a minus sign an increase in the current flowing towards the Southern Hemisphere. It is seen from Table 6 that for both stations the potential gradient of the current flowing towards the Southern Hemisphere, on the average, is increased in the summer and decreased in the winter months.

18. The Fourier analysis (Table 7) of the annual variations given in Table 6 likewise shows that excepting as to the fourth term, there is practically no correspondence between dX and dW. On the other hand, the correspondence in phase for the principal terms (first two) between dY and dN is fairly good, though the ratio of the respective amplitudes c_1/c_2 differ as 1.1 to 2.9. If the dW and dN were the result of variations in the Earth's magnetism, then they should show some decided relationship to the derivatives $d(dX)/d\theta$ and $d(dY)/d\theta$, respectively, but evidently this is not the

case. *We must accordingly conclude that the annual variations, observed at the Ebro Observatory, of the potential gradients of the earth currents and of the components of the Earth's magnetism, may be related to one another as cause and effect only to a very minor extent: both sets of variations may have to be referred, more or less, to common causes.*

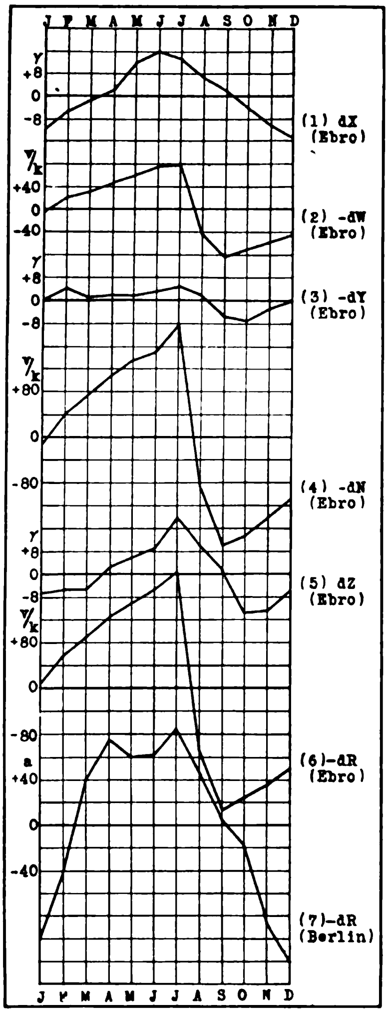


FIG. 1—Annual Variation of Earth-Current Potential-Gradients and of Magnetic Components.

19. Fig. 1 is a graphical representation of the data in Table 6. The chief facts shown by the various curves have already been stated in the preceding paragraphs. It should be noted that Curves 2, 3, 4, 6, and 7 have been plotted inverted. The annual variation, dR, of Weinstein's resultant current at Berlin, given in the last column of Table 6, follows a somewhat similar course to the annual variation dR, of the resultant current at Ebro (see curves 6 and 7), though there are some discordances, to be referred possibly to local or disturbing causes. From Curves 2, 4, and 6, it is seen that the annual variation in the Ebro currents, as already pointed out in paragraph 16, is most marked between July and September; it would be of interest to know whether there are any local contributing causes, such as meteorological ones, for example.

TABLE 7.—*Fourier analysis of annual variation of magnetic and electric components at the Ebro Observatory for the magnetically-calm days, 1914–1918.*

[Annual variation, dX, dW, etc. $= c_1 \sin(\theta + \phi_1) + c_2 \sin(2\theta + \phi_2) \ldots$; θ is counted from midnight of Dec. 31, at rate of 30° per average month.]

Quantity	Mag. Comp.	Elec. Comp.	Mag. Comp.	Elec. Comp.	Mag. Comp.	Res. El. Comp. Ebro	Res. El. Comp. Berlin
	dX	dW	dY	dN	dZ	dR	dR
	γ	v/k	γ	v/k	γ	v/k	v/k
c_1	13.4	72.8	3.7	169	11.9	192	94
c_2	0.4	26.6	3.2	59	5.7	63	27
c_3	2.1	17.8	1.3	38	2.8	42	12
c_4	0.4	12.1	1.0	31	0.8	37	10
c_1/c_2	36.1	2.7	1.1	2.9	2.1	3.0	3.5
	°	°	°	°	°	°	°
ϕ_1	279	148	152	146	278	148	107
ϕ_2	48	277	245	269	52	266	107
ϕ_3	317	87	15	73	140	86	45
ϕ_4	208	210	105	204	45	204	217

Diurnal Variation of the Magnetic and Electric Components.

20. Table 8 contains the diurnal-variation data for the magnetic components (X, Y, Z) and for the electric quantities (N, W, R, A), as derived from the Ebro magnetic observations and earth-current measurements with the aid of the formulæ given in paragraph 9, all for the magnetically-calm days (5 per month), 1914–1918. The data were obtained for the 4 winter months (Group I), November–February; (Group II), for the spring and autumn months, March, April, September, and October; and

TABLE 8.—*Mean diurnal variations for the year of the magnetic and electric components at the Ebro Observatory for the magnetically-calm days, 1914–1918.*

[Meaning of signs: +, numerical increase of X and Z, and algebraic increase of Y, W, N, and R, since the values of the latter quantities, according to paragraph 10 and Tables 2, 3, and 4, are all negative. A − sign of ΔA means a change in azimuth of resultant, R, from South towards East.]

G.M.T.	Mag.	El.	Mag.	El.	Mag.	El. Resul.		G.M.T.	Mag.	El.	Mag.	El.	Mag.	El. Resul.	
	ΔX	ΔW	ΔY	ΔN	ΔZ	ΔR	ΔA		ΔX	ΔW	ΔY	ΔN	ΔZ	ΔR	ΔA
h	γ	v/k	γ	v/k	γ	v/k	′	h	γ	v/k	γ	v/k	γ	v/k	′
1	+0.2	−1.0	+4.3	−1.8	+3.9	−2	−2	13	−2.3	−2.4	−28.6	−7.4	−13.3	−7	−26
2	+0.3	−0.7	+4.2	−1.1	+3.9	−1	0	14	−3.3	+0.9	−26.1	+1.5	−8.2	+2	−9
3	+0.3	−0.4	+4.2	−0.3	+3.9	−1	+3	15	−3.9	+3.6	−18.5	+8.3	−2.3	+9	+16
4	+1.4	+0.8	+5.2	+2.4	+4.4	+3	+7	16	−3.0	+5.1	−9.9	+12.1	+2.2	+13	+25
5	+2.4	+1.7	+7.9	+4.5	+5.1	+5	+11	17	−1.1	+5.0	−4.0	+11.7	+4.6	+13	+23
6	+2.8	+1.7	+12.1	+4.7	+5.3	+5	+13	18	+1.4	+4.4	−1.0	+10.3	+5.2	+11	+20
7	+1.7	+1.3	+17.0	+3.9	+4.8	+4	+11	19	+3.4	+2.7	−0.1	+6.4	+4.7	+7	+11
8	−1.1	+0.4	+21.8	+1.5	+2.8	+1	+5	20	+4.5	+1.4	+1.0	+3.9	+4.3	+4	+10
9	−4.9	−3.4	+20.6	−8.0	−3.0	−9	−8	21	+4.6	+0.1	+1.7	+1.0	+3.8	+1	+6
10	−6.9	−6.5	+9.1	−16.6	−10.3	−18	−37	22	+4.7	−0.6	+2.5	−0.7	+3.3	−2	+3
11	−5.8	−6.8	−8.0	−18.2	−15.1	−19	−44	23	+4.4	−1.2	+3.1	−1.9	+3.0	−2	+2
12	−3.5	−5.1	−22.2	−14.2	−16.0	−15	−38	24	+3.9	−1.2	+3.6	−2.1	+2.8	−2	0

TABLE 8*a*.—*Values of* $\Delta Y'$ *and of* ΔD *for the Ebro Observatory. 1914–1918.*

[+ means motion of north end of magnetic needle towards East.]

G.M.T.	ΔY′	ΔD	G.M.T.	ΔY′	ΔD	G.M.T.	ΔY′	ΔD	G.M.T.	ΔY′	ΔD	G.M.T.	ΔY′	ΔD	G.M.T.	ΔY′	ΔD
h	γ	′	h	γ	′	h	γ	′	h	γ	′	h	γ	′	h	γ	′
1	+0.7	+0.6	5	+3.2	+1.2	9	−6.9	+2.8	13	−2.2	−4.2	17	+4.1	−0.6	21	+1.2	+0.4
2	+0.5	+0.6	6	+5.9	+1.8	10	−14.4	+1.1	14	+6.0	−3.9	18	+1.4	−0.1	22	+0.6	+0.5
3	+0.2	+0.6	7	+6.0	+2.5	11	−16.5	−1.3	15	+9.3	−2.8	19	+0.8	+0.1	23	+0.2	+0.6
4	+0.9	+0.8	8	+1.4	+3.1	12	−11.4	−3.3	16	+7.7	−1.5	20	+1.1	+0.3	24	+0.3	+0.6

(Group III), for the 4 summer months, May–August. Finally, the data for the whole year, and for the entire period 1914–1918, were obtained and these alone are given in Table 8. The significance of the signs, as stated at the top of the table, is in accordance with paragraph 10. The geographic position of the Ebro Observatory is 40° 49′ N, and 0° 31′ E. Accordingly, G. M. T. hours are within two minutes of the local hours.

Table 9 contains the results of the Fourier analysis of the diurnal variations of the magnetic and electric data given in Table 8, as also of the potential gradient, P, of atmospheric electricity at Ebro for the mean of the years, 1914–1918. For the purpose of comparison, the last two columns are added, based upon Weinstein's Berlin data (1884–1887) as given by Chree[8]; the quantities

[8] *Encycl. Brit.*, 11th ed., vol. 8, p. 815.

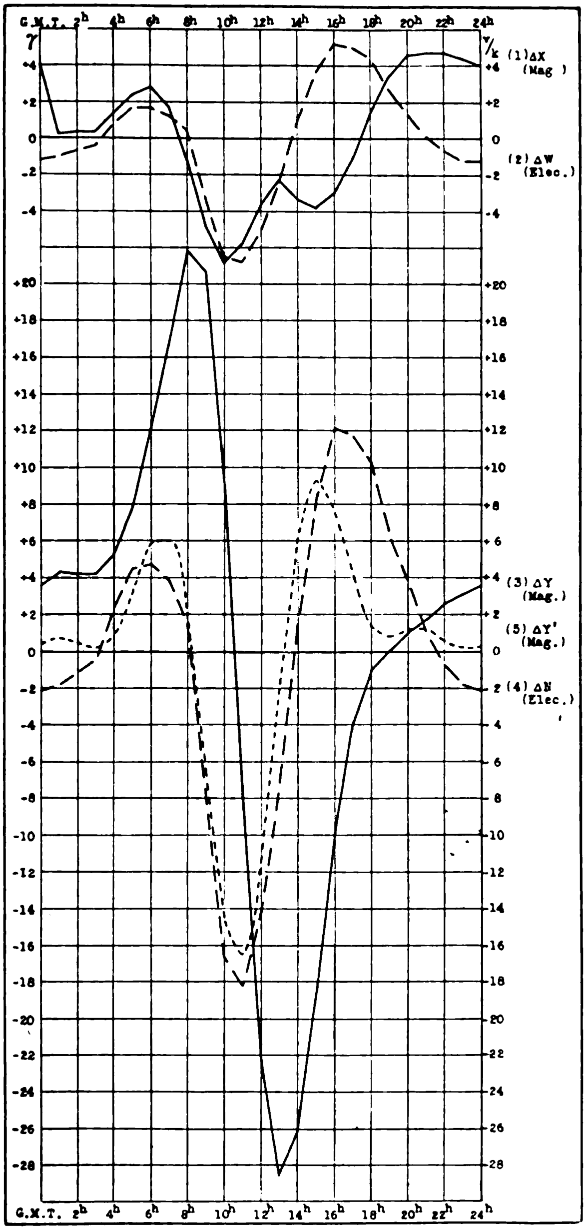


FIG. 2.—Diurnal Variation of Horizontal Magnetic Components and of Earth-Current Components.

apply to the astronomical directions and are expressed in arbitrary units, *a*.

21. Fig. 2 shows the curves based on the data in Table 8. It is seen that while there is some general agreement in Curves 1 and 2 (ΔX and ΔW), they cannot be related as effect and cause, respectively, as would be the case, if ΔX were simply the magnetic effect of ΔW. Not only is the principal minimum of the two curves displaced about an hour with reference to one another, that for the electric curve occurring later, but the curves show a marked discordance for the portion of the day between 14^h (2 P. M.) and midnight. The same general facts are disclosed by the curves, not given here, which were drawn for the separate Groups I, II, and III. Both the magnetic and the electric curves show a greater development during the summer months (Group III) than for the winter months (Group I).

22. Passing next to Curves 3 and 4, ΔY and ΔN, each shows a much greater development than was the case for the previous curves. While again there is some similarity between ΔY and ΔN, the principal maxima and minima of the ΔN-curve occur about two hours earlier than those for the ΔY-curve. Thus again no direct relationship is indicated between the electric variation (ΔN) and the magnetic variation (ΔY), as cause and effect, respectively. If now we compare the $\Delta Y'$-curve (No. 5) showing the rate of change per hour in the west-east magnetic component, a striking similarity is found between $\Delta Y'$ and ΔN. Curve 5 was drawn by aid of computed quantities derived from the Fourier coefficients (see Tables 8*a* and 9). The principal minimum of Curves 4 and 5 occurs at the same time; the principal maxima of the two curves are displaced with reference to one another about one hour, first in one direction, then in the opposite direction. *The general conclusion is that the north-south earth-current might be the result of electro-magnetic induction, caused by the fluctuation during the day of the west-east component of the Earth's magnetism.*[9]

As in the case of Curves 1 and 2, the development of Curves 3, 4, and 5, is greater for the summer (Group III) than for the winter months (Group I).

23. Fig. 3 shows the diurnal-variation curves, ΔZ and ΔR. A general similarity between the magnetic and the electric curves is again evident; however, the displacement of the principal maxima and minima is about two hours, those of the electric curve (2)

[9] *Cf.* STEINER, L.: On Earth-Currents and Magnetic Variations; *Terr. Mag.*, vol. 13, 1908, pp. 58-62.

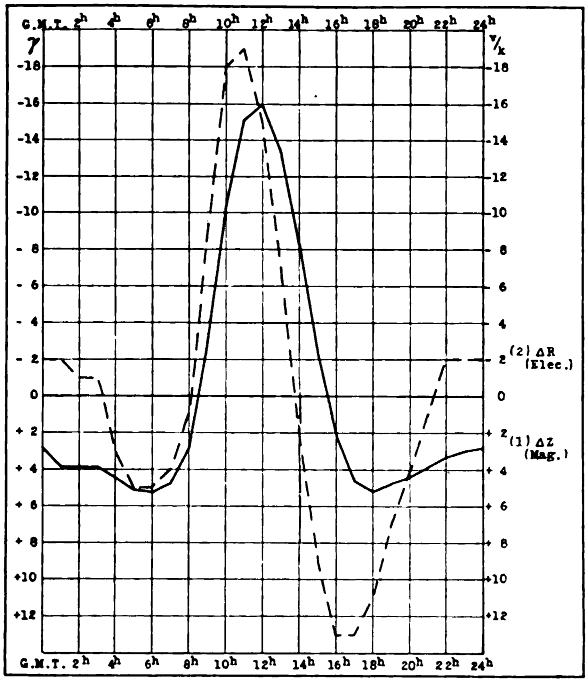


FIG. 3.—Diurnal Variation of Vertical Magnetic Component and of Resultant Earth-Current Potential-Gradient.

occurring earlier than those of the magnetic curve 1. Thus, an immediate relationship between the diurnal variation of the resultant horizontal potential-gradient of the earth-current and the diurnal variation of the vertical component of the Earth's magnetism, as cause and effect, is not disclosed. The development of both $\triangle Z$ and $\triangle R$ is greater in summer (Group III) than in winter (Group I).

24. Figs. 4-7 show the horizontal-vector diagrams for the years 1914 (one year after year of minimum sun-spot activity) and 1917 (the year of maximum sun-spot activity). Figures 4 and 7 represent the $\triangle X$ and $\triangle Y$ magnetic variations, whereas 5 and 6 show the $\triangle N$ and $\triangle W$ electric variations. Both pairs of curves show the largest development during the year of maximum sun-spot activity, the relative enlargement of diagram-area for 1917 over that for 1914 being approximately the same for the magnetic and the electric curves.

There is a striking difference between the magnetic diagrams

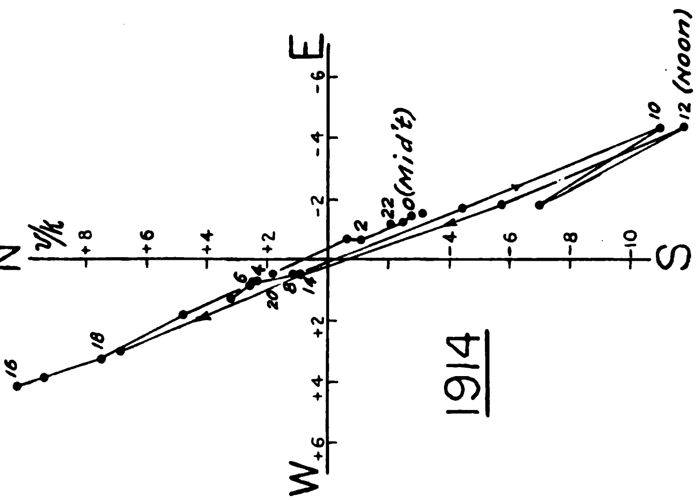


FIG. 5.—Earth-Current Vector-Diagram of Diurnal Variation of North (N) and West (W) Components for 1914 and the Ebro Observatory.

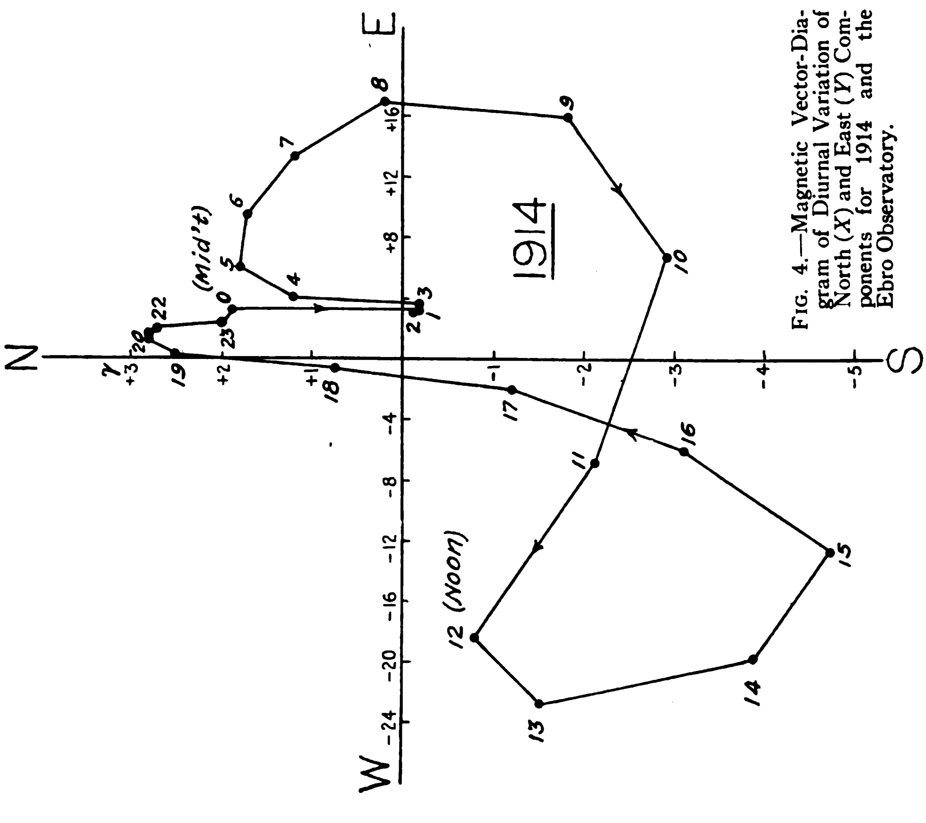


FIG. 4.—Magnetic Vector-Diagram of Diurnal Variation of North (X) and East (Y) Components for 1914 and the Ebro Observatory.

(Figs. 4 and 6) and the electric diagrams (Figs. 5 and 7). While the former are somewhat symmetrical about the true meridian (NS-line), the latter are symmetrical about a line running, on the average, from about 24° E of S to about 24° W of N, which is approximately the direction towards the Magnetic North Pole (see paragraph 11). The development of the electric diagrams at right angles to this direction, as is seen, is very limited. It will be seen that the general direction in which both the magnetic and the electric vector-diagrams are described is for the greater part the same as that of the hands of a clock.

Fig. 8 exhibiting the diurnal changes in the magnetic declination and in the direction of the resultant horizontal earth-current once more emphasizes some of the difficulties of associating the earth-current and the magnetic phenomena as cause and effect. It will be seen that the character of the electric curve is considerably different from that of the magnetic curve; for the former the amplitude of the 12-hour wave is larger than that of the 24-hour one, whereas for the latter, just the reverse is the case.

25. Fig. 9 shows that there is as good an agreement between the results of the earth-current measurements at Ebro and Berlin, as could be expected, especially if the difference in method of measurement and local conditions be taken into account.

26. The Fourier analyses of the diurnal variations, as given in Table 9, once more confirm the chief facts set forth in the preceding paragraphs. There is no general agreement in the phase angles and relative amplitudes for $\triangle X$ and $\triangle W$, nor for $\triangle Y$ and $\triangle N$, nor for $\triangle Z$ and $\triangle R$. There is, however, a better agreement in the phase-angles and relative amplitudes for the $\triangle Y'$ (time derivative of $\triangle Y$) and $\triangle N$; but the agreements are not sufficiently close to enable one to draw a final conclusion as to the precise relation between $\triangle Y'$ and $\triangle N$.

27. Comparing the colums $\triangle W$ and $\triangle N$ for Ebro with the corresponding ones for Berlin, a general agreement is evident. The phase-angles are practically in agreement for local mean time at each station; if they are referred to the same time (G. M. T.) the agreement in some of the phase-angles is somewhat improved, as though a portion of the diurnal variation of earth currents may progress according to universal time, rather than local time. It is unfortunate for the settlement of this extremely interesting question that sufficiently extensive earth-current data for a station

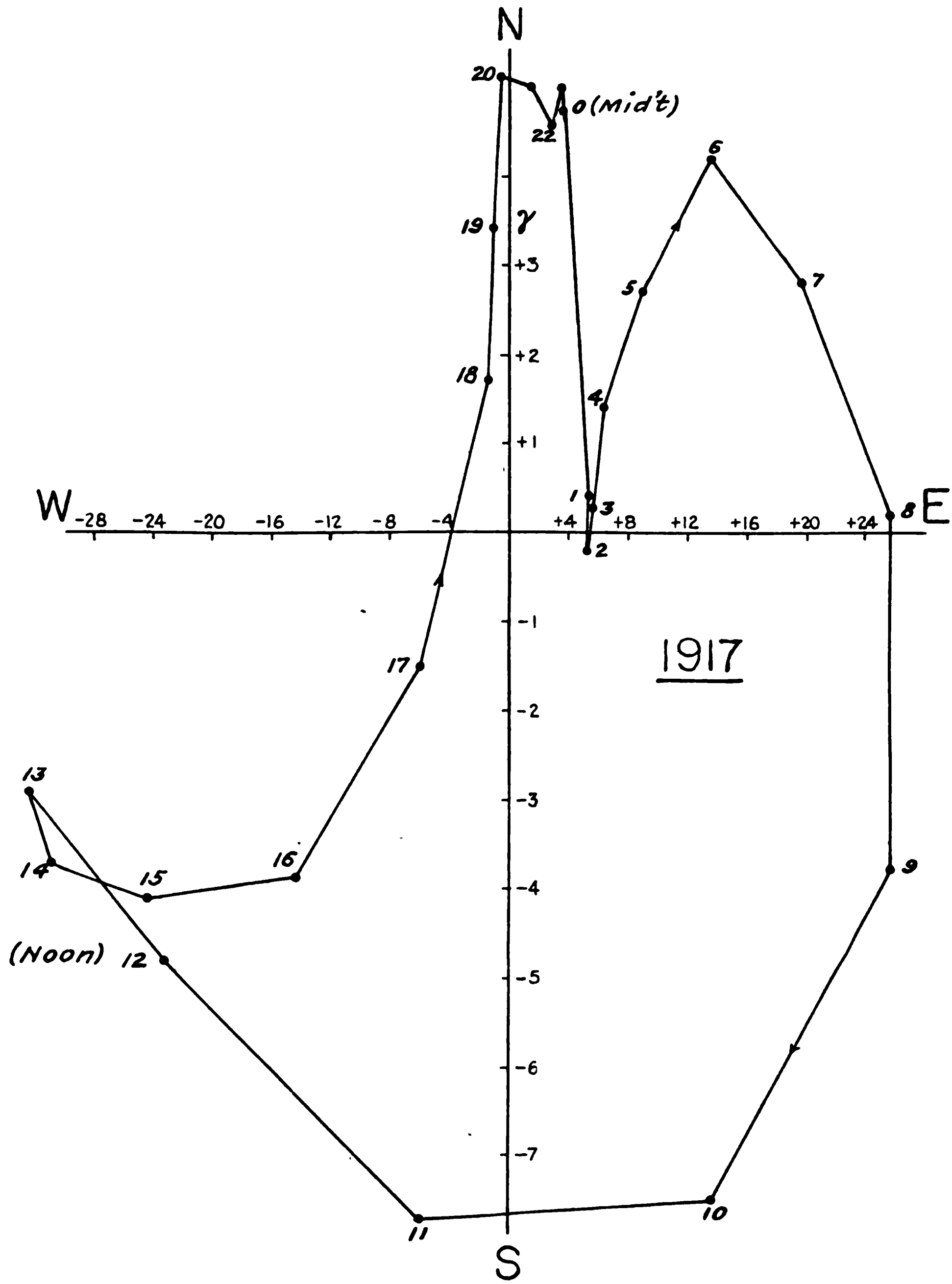


FIG. 6.—Magnetic Vector-Diagram of Diurnal Variation of North (X) and East (Y) Components for 1917 and the Ebro Observatory.

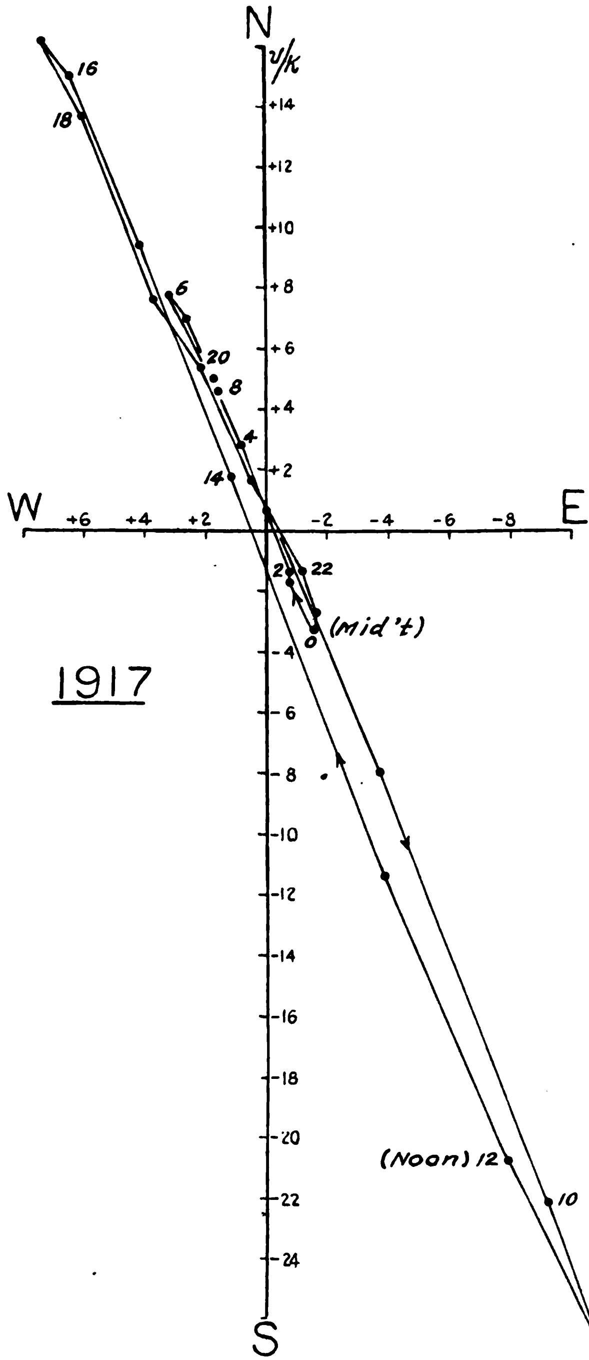


FIG. 7.—Earth-Current Vector-Diagram of Diurnal Variation of North (*N*) and West (*W*) Components for 1917 and the Ebro Observatory.

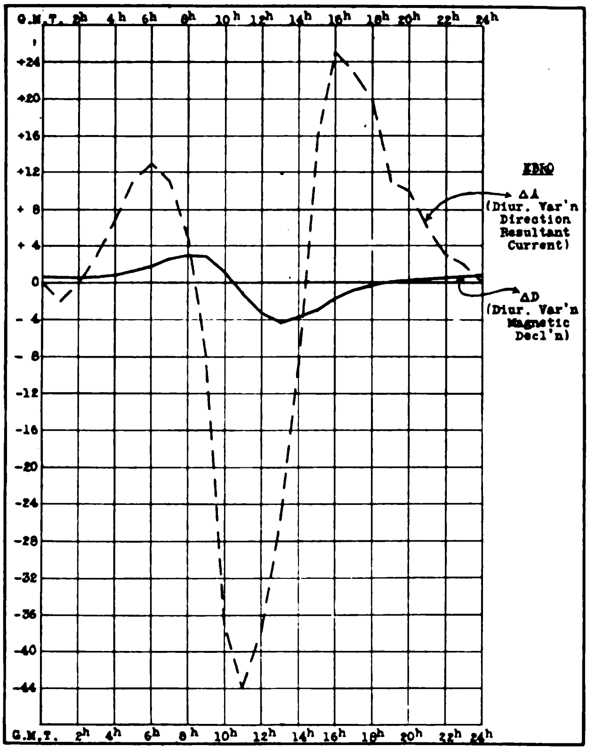


FIG. 8.—Diurnal Variation of Magnetic Declination and of Direction of Resultant Earth-Current for 1914-1918 and the Ebro Observatory.

differing more widely in longitude from Ebro, than Berlin, are not available.

28. It is also of interest to compare the results of the Fourier analysis of the atmospheric-electric potential-gradient, ΔP, at Ebro, given in Table 9, with those for the earth-current diurnal variation (ΔW, ΔN, ΔR) at the same station. There is no agreement in phase-angles except approximately for the fourth term.

29. *The average diurnal-variation quantity, or average departure* (A. D.) of any element from its mean value for the day, regardless of sign, was computed for each month of the 5 years, 1914–1918. The mean values of these quantities are given in Table 10 for the magnetic components X, Y, and Z, first according to season, and next for each year. The figures in column "Win.", are for the 4 months (Nov.–Feb., Group I); those in column "S A" are for

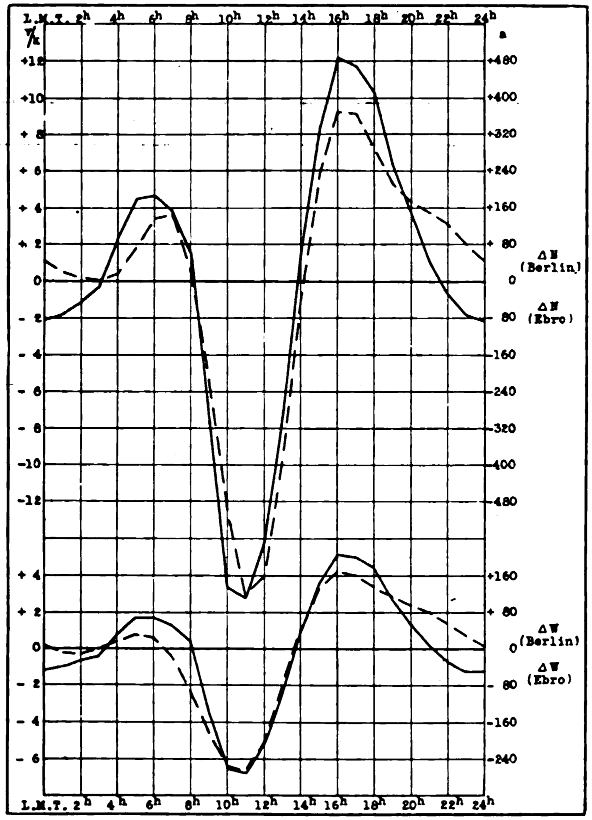


FIG. 9.—Diurnal Variation of Earth-Current Components for the Ebro Observatory, 1914-1918, and for Berlin (Weinstein data, 1884-1887).

TABLE 9.—*Fourier analysis of the diurnal variation of the magnetic and electric components at Ebro Observatory for the magnetically-calm days, 1914–1918.*

Quantity	Magnetic (Ebro)				Electric (Ebro)				Elec. (Berlin)	
	ΔX	ΔY	ΔZ	$\Delta Y'$	ΔW	ΔN	ΔR	ΔP	ΔW	ΔN
	γ	γ	γ	γ	v/k	v/k	v/k	V/m	*a*	*a*
c_1	4.13	12.76	7.19	12.76	2.09	5.34	4.79	19.42	122.9	241.7
c_2	1.58	11.41	5.96	22.82	3.63	9.02	8.95	15.76	106.7	265.0
c_3	1.76	6.65	2.55	19.95	1.41	3.84	3.64	2.81	50.8	163.6
c_4	1.10	2.17	0.74	8.68	0.38	1.07	0.94	6.77	10.9	49.3
c_1/c_2	2.62	1.12	1.21	0.56	0.58	0.59	0.53	1.23	1.2	0.9
	°	°	°	°	°	°	°	°	°	°
ϕ_1	99.0	34.8	90.0	124.8	151.3	141.2	146.3	209.6	143.0	126.5
ϕ_2	236.4	219.5	273.4	309.5	297.4	295.5	296.5	196.4	303.5	286.3
ϕ_3	199.4	52.9	95.8	142.9	125.5	124.4	125.1	284.6	147.8	114.8
ϕ_4	61.4	245.5	303.0	335.5	350.7	335.4	342.8	331.0	315.8	295.6

Variations During the Year and the Sun-spot Cycle.

TABLE 10.—*Average departure of diurnal-variation quantities at the Ebro Observatory for the magnetically-calm days, 1914–1918.*

Quantity		For Season			For Year				
		Win.	S. A.	Sum.	1914	1915	1916	1917	1918
		γ	γ	γ	γ	γ	γ	γ	γ
Mag. Component.......	X	4.1	4.2	**4.5**	3.6	3.8	**5.1**	4.9	3.9
	Y	6.5	12.0	**13.2**	7.9	9.6	10.9	**11.9**	10.6
	Z	3.1	6.8	**7.5**	4.5	4.8	6.4	**6.8**	6.5
		v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k
Elec. Resultant	R	6.9	8.8	**9.7**	6.0	8.0	8.4	**10.2**	9.6

the 2 Spring months and 2 Autumn months (Mar., Apr., Sep., Oct., Group II); and those in column "Sum." are for the 4 months (May–Aug., Group III). For the diurnal variation of the earth-current potential-gradients, the average departures were deduced from the published potential-gradient along the N′S′ line (see paragraph 7); the quantities so obtained may be regarded as practically the same as what they would be for the resultant horizontal potential-gradient, R, for the reason stated in paragraph 12.

It will be seen that the average-departure quantities, for both terrestrial magnetism and earth currents, are largest for the summer and vary during the sun-spot cycle, increasing, in general, with increased sun-spot activity, maximum sun-spot activity having occurred in 1917.

30. Table 11 was drawn up with the aid of the published values of the extreme diurnal range (difference between recorded maximum and minimum potential-gradients during the day) of the earth-current measurements along the N′S′ line (paragraph 7) for each day and for the entire period, 1910–1920. The mean monthly and annual values of these ranges are given, I, taking all days into consideration, and II, taking only the comparatively undisturbed days, namely, those designated as of electric character 0 and 1. According to paragraph 12 we may regard the ranges for the component N′S′ as approximations, sufficient for our purposes, to the ranges for the resultant horizontal potential-gradient, *R*.

It will be seen that the extreme diurnal range of the Ebro earth-current potential-gradients reaches its highest values near the equinoctial months, and that it varies during the sun-spot cycle, the minimum value occurring near the year (1913) of sun-spot minimum and the maximum near the year (1917) of sun-spot maximum.

TABLE 11.—***Variation in extreme diurnal range of resultant horizontal potential-gradient of earth currents at the Ebro Observatory, 1910–1920, in millivolts per kilometer.***

For	Variation in Range During the Year, 1910–1920.											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k
I. All Days...	*84*	*84*	**103**	96	*87*	90	90	100	100	**113**	96	87
II. Days (0, 1).	*60*	67	74	**75**	*67*	68	76	78	73	**83**	67	*60*
	Variation in Range During the Sun-spot Cycle.											
	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	Mean
I. All Days...	70	85	68	*61*	73	94	114	113	113	**130**	114	94
II. Days (0, 1).	69	62	*57*	58	62	72	85	**89**	83	84	58	71

31. The maximum range for Series I (All Days) occurred in 1919, or two years subsequent to the year of sun-spot maximum, whereas for the undisturbed days alone (Series II), the maximum range occurred in the same year as the sun-spot maximum. *Series I shows the effect of disturbances, as the result of which earth currents are generated that die out but gradually and cause a lag in the maximum. There is a similar lag in polar-light frequencies at the time of maximum sun-spot activity.*

32. In order to study more closely the annual variation in the

TABLE 12.—***Annual variation of diurnal range of earth-currents and of atmospheric-electric potential-gradients at Ebro, 1910–1920, compared with annual variation of Aurora-Borealis frequency and of terrestrial magnetic disturbances.***

Month	Ebro E. C. (R) Days		Ebro A. E. Days 0, 1	Aur. Bor. 58°–51°	M. C. 1910 to 1920
	0, 1	All			
	v/k	v/k	V/m		
Jan.......	*60*	*84*	*111*	9.4	0.61
Feb.......	67	84	125	11.8	0.65
Mar......	74	**103**	**129**	**12.2**	**0.70**
Apr.......	**75**	96	109	10.0	0.62
May......	*67*	*87*	96	2.8	0.62
Jun.......	68	90	90	*0.4*	*0.53*
Jul.......	76	90	*87*	1.2	0.55
Aug......	78	100	91	5.3	0.65
Sep.......	73	100	108	13.6	0.67
Oct.......	**83**	**113**	**139**	**15.0**	**0.72**
Nov......	67	96	129	10.9	0.61
Dec.......	*60*	87	126	*8.2*	*0.60*
Mean.....	71	94	112	8.4	0.63
Curve.....	(1)	(3)	(2)	(4)	(5)

range of the earth-current potential-gradients and to see how it may be related to other geophysical phenomena, Table 12 was prepared for the construction of Fig. 10. The data in column 4 are according to Ellis[10] for the region 58° N—51° N, and those in column 5 are the mean magnetic character numbers for the 11-year cycle, 1910–1920, which may serve as measures of terrestrial magnetic disturbances in the course of the year. It will be seen from an inspection of Fig. 10 that all curves show maxima near the

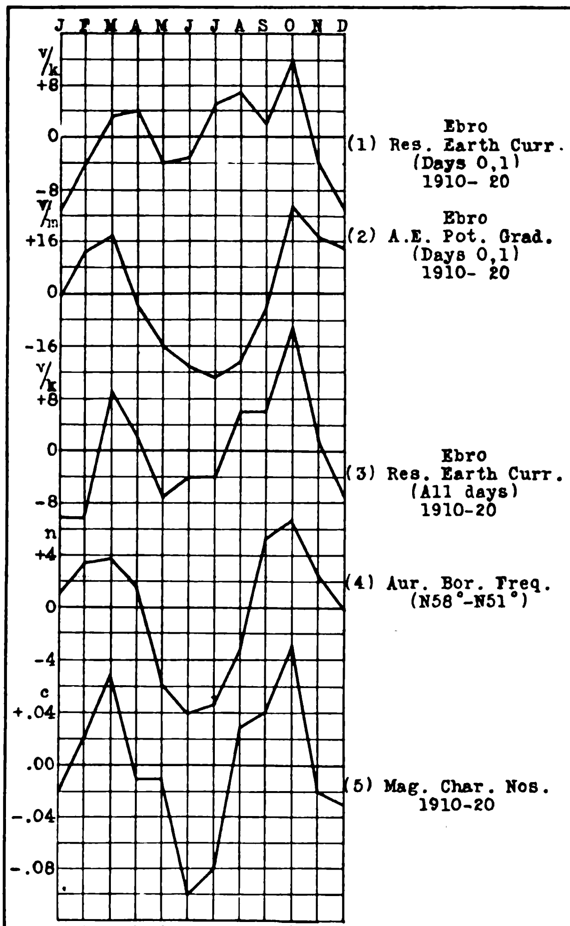


FIG. 10—Annual Variation of Diurnal Range of Electric and Magnetic Phenomena.

[10] *Mon. Not. R. A. S.*, 1904, p. 229.

equinoctial months and minima near the solstitial months, and what is of especial interest, *the principal maximum for each curve occurs in October, thus exhibiting a lag of about a month with respect to the autumn equinox. Thus earth currents, atmospheric electricity, the Aurora Borealis and the Earth's magnetic disturbances, all show closely similar annual variations in the ranges of their fluctuations.*

33. It will be of interest here to recall that Tromholt[11], who investigated disturbances in telegraph lines at four stations in Norway during three years, 1881–1884, found "that the periods of the telegraphic disturbances are identical with those of the Aurora Borealis, i. e., that their minima occur at the solstices, and their maxima at the equinoxes".

Annual Changes During the Sun-spot Cycle.

34. Table 13 shows how the potential-gradients of earth currents and of atmospheric electricity change from year to year during the 11-year sun-spot cycle, 1910–1920, for the electrically-undisturbed days (character 0 and 1). In the first two rows are the available earth-current data as obtained from the Ebro bulletins; these apply to the directions of measurement, $N'S'$ and $W'E'$ (see paragraph 7). The directions and signs have been reversed in our table in order to conform to the conventions adopted in paragraph 10. The values of α (angle between $N'S'$ and R, resultant), R, A, N, and W, were then computed with the aid of Father Ubach's formulæ and those given in paragraph 9. For the years where values of W were lacking, it was necessary to adopt mean values of α (3°.9) and of A (29°.2) obtained from the years of complete measurements, 1913–1918. The quantities thus derived are shown in parentheses; they are probably correct within 2 units for the reason stated in paragraph 12. For 1910, owing to various reasons, all the results may be so uncertain, as to necessitate their being left out of consideration here. A sign was also given to R in order to indicate that the resultant current flows towards the Southern Hemisphere.

The annual values of the potential-gradient of atmospheric electricity are complete for the entire period. The bottom rows contain the Wolfer sun-spot numbers and the D-measure (average departures of daily sun-spot numbers from monthly mean)[12] for 1910–1920.

[11] *Tromholt, S.*, Under the rays of the Aurora Borealis, vol. 1, 1885, pp. 276-282.

[12] BAUER, L. A., *Terr. Mag.*, vol. 26, 1921, p. 47.

TABLE 13.—*Annual changes during sun-spot cycle, 1910–1920, of earth-current potential-gradients, in millivolts per kilometer, and of atmospheric-electric potential-gradients, in volts per meter, at the Ebro Observatory, for the electrically undisturbed days.*

Quantity	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	Remarks
S'N' = N'	−136	.....	*−448*	−297	−357	−255	−213	−187	**−155**	−289	−370	Earth Currents
E'W' = W'	....	.....	....	− 26	− 20	− 25	− 18	− 13	**− 12**	....	....	
S N = N	(−119)	.....	*(−392)*	−259	−316	−221	−186	−164	**−135**	(−252)	(−323)	
E W = W	(−66)	.....	*(−219)*	−148	−167	−130	−106	−90	**− 75**	(−141)	(−181)	
R	(−136)	.....	*(−449)*	−298	−357	−256	−214	−187	**−155**	(−290)	(−371)	
α	....	.....	....	4°.5	2°.6	5°.1	4°.3	3°.4	3°.8	....	....	
A (E of S)	....	.....	....	29.7	27.9	30.4	29.6	28.7	29.0	....	....	
Pot. G...	113	116	113	110	*109*	111	121	**130**	126	110	109	At. Elec.
S. N.....	18.6	5.7	3.6	*1.4*	9.6	47.4	57.1	**98.8**	77.6	63.1	38.7	Solar Activity
S. D.....	10.7	5.5	3.9	*2.1*	7.2	21.2	24.7	**29.6**	26.0	21.9	17.2	

35. It will be seen from the table that the earth-electric components tend to decrease numerically, or increase algebraically, with increased sun-spot activity, i. e., *the potential-gradients in the direction of the normal flow of the earth currents at Ebro, namely, towards south and east, decrease as sun-spot activity increases. The lowest numerical values are reached in 1918, or a year subsequent to that of sun-spot maximum. Once more, accordingly, there is evidence of a lag in earth currents with increased solar activity* (see also paragraph 31). The conclusion apparently resulting was expressed as follows in my 1921 paper[13]:

"The Earth's magnetic energy and average intensity of magnetization, as well as the strength of the normal electric currents circulating in the Earth's crust, suffer a diminution during increased solar activity. The electric currents induced in the Earth during periods of increased solar activity are in general reversed in direction to the normal currents, the strength of these superposed currents increasing with increased solar activity."

36. It may be pointed out that the two phenomena stated in this conclusion—diminished intensity of magnetization of the Earth and diminished strength of the normal earth-electric currents—are not in harmony with each other and, in consequence, cannot be related as cause and effect. The diminished intensity of magnetization is caused chiefly by diminution in the north magnetic component, X, and this, in accordance with paragraph 10, would imply a diminished electric current towards the West, instead of towards the

[13] *Terr. Mag.*, vol. 26, 1921, p. 67.

East, as shown by the quantities in Table 13. If we may place full reliance on the earth-electric quantities, it is seen again, as in paragraphs 18, 21, and 22, that *a causal relationship between certain phenomena of terrestrial magnetism and earth currents cannot be immediately concluded to exist, except in a minor degree. It would seem rather that the variations of both the magnetic and the electric phenomena are the effects of a common cause.*

37. It is extremely unfortunate for further investigation of these important indications, that no other series of earth-current observations as extensive as those at Ebro, are available. Could reliance be placed on values given by Weinstein (see paragraph 13) for the "constant" currents measured at Berlin, 1884–1887, we would have to conclude that the numerical values decrease with decreased sun-spot activity, the year 1883 having been that of sun-spot maximum.

38. *Passing next to the potential gradients of atmospheric electricity, it is seen that a minimum value (109) in 1914 and a maximum value (130) in 1917 are clearly shown, thus indicating increased potential gradient with increased sun-spot activity.* For further evidence of this indicated fact, the interested reader may be referred to my 1921 article.[14]

39. If the phenomena of atmospheric electricity are, indeed, related to solar activity, new points of view as to the origin and maintenance of the Earth's supposed electric charge are disclosed, as already indicated in my previous papers[15]. Accordingly, a Fourier analysis has been made of the diurnal variation (mean of year) of the atmospheric-electric potential-gradient at Ebro for the whole 11-year series, 1910–1920. The resulting quantities will be found in Table 14, which will require no further explanation, the formulæ used being stated at the head of the table.

It will be noticed that the analysis was extended to the sixth term (4-hour wave) inclusive, as for each year a marked increase in the amplitude, c, of the fourth term (6-hour wave) was unmistakably shown. The minimum amplitude, c_1, of the 24-hour wave, occurred in 1912 and the maximum in 1917; the same facts are shown by the amplitude c_4 of the 6-hour wave, which appears to be of extreme interest (see paragraph 28, and values of ϕ_4 for $\triangle Y'$, $\triangle R$, and $\triangle P$, Table 9). The tentatively combined amplitude, c_r, also shows a minimum amplitude in 1912 (one year prior

[14] *Terr. Mag.*, vol. 26, 1921, pp. 63 and 64, and Fig. VII.

[15] *Terr. Mag.*, vol. 25, 1920, pp. 156-162, and vol. 26, 1921, pp. 33-42, and 67-68.

to that of sun-spot minimum) and a maximum amplitude in 1917 (year of sun-spot maximum). *There can hardly be any question, therefore, that the atmospheric-electric potential-gradient at Ebro is subject to a diurnal fluctuation, the amplitude of which increases, as in the case of that of earth currents and terrestrial magnetism, with increased sun-spot activity.*

To find relations between atmospheric-electric phenomena and solar activity, it is essential to select a station as free as possible from meteorological disturbing influences. Such a station the Ebro observatory appears to be.

TABLE 14—*Fourier Analysis of diurnal variation of potential gradient (P) at Observatorio del Ebro, Tortosa, Spain, 1910–1920, for the electrically-undisturbed days (character 0, 1).*

$\triangle P = a_1 \cos \theta + b_1 \sin \theta + a_2 \cos 2\theta + b_2 \sin 2\theta \ldots\ldots = c_1 \sin(\theta + \phi_1) + c_2 \sin(2\theta + \phi_2) \ldots$; θ is counted from 0^h, midnight, G. M. T.

$$c_r = \sqrt{c_1^2 + c_2^2 + c_3^2 + c_4^2 + c_5^2 + c_6^2}$$

Quant.	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	Mean
	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m
c_1	17.2	16.3	*14.6*	18.0	18.0	18.7	16.4	**23.4**	20.8	17.3	20.9	18.2
c_2	11.7	17.9	14.5	14.7	14.3	17.4	15.7	16.6	15.3	15.4	15.4	15.3
c_3	3.0	1.6	1.5	1.7	3.5	4.2	2.0	2.2	3.5	1.2	5.6	2.5
c_4	7.0	6.4	*5.2*	5.8	6.0	6.4	7.1	**8.3**	6.2	5.6	6.0	6.4
c_5	0.5	1.0	1.3	1.6	0.7	1.8	2.3	1.8	2.2	0.9	2.4	1.3
c_6	2.3	2.3	1.3	1.8	1.5	0.7	2.1	1.7	0.6	1.2	0.7	1.4
c_r	22.3	25.2	*21.4*	24.1	24.1	26.7	24.0	**30.0**	26.9	23.9	27.3	24.8
	°	°	°	°	°	°	°	°	°	°	°	°
ϕ_1	196	202	208	213	212	204	209	211	211	212	213	209
ϕ_2	199	194	190	192	186	193	199	207	196	185	190	194
ϕ_3	282	248	260	286	252	294	255	313	304	282	310	286
ϕ_4	326	330	334	329	326	332	336	334	325	324	325	329
ϕ_5	351	139	153	130	70	79	117	115	124	102	95	112
ϕ_6	92	100	122	98	77	104	97	108	50	90	70	95

Chief Conclusions.

40. With the aid of the highly valuable and promptly published series of observations of earth currents, terrestrial magnetism, and of the atmospheric-electric elements, made at the Observatorio del Ebro, Tortosa, Spain, for a complete sun-spot cycle, it has been possible not only to confirm and extend certain results previously reached by others, but also to draw important new conclusions. The successive directors and members of the scientific staff of the Observatorio del Ebro deserve great credit for making readily accessible the results of their comprehensive and valuable observa-

tional work in geophysics and astrophysics. For the first time it has been possible to make comparisons between the phenomena of terrestrial magnetism, earth currents, and atmospheric electricity, as observed at the same station.

The author also wishes to acknowledge his indebtedness to members of the computing staff of the Department of Terrestrial Magnetism, especially to Messrs. Duvall, Ennis, and Peters, and to Miss Tibbetts; without their effective cooperation the extensive computational work required could not have been so expeditiously accomplished. To Mr. Ennis also must be given credit for the preparation of the diagrams appearing in this paper.

It is hoped that the present investigation, which had to be confined to a discussion of the observational data on magnetically-calm, or on electrically-calm days, may be supplemented later by a discussion of earth-current data on disturbed days.

The chief conclusions may be stated as follows:

a. The resultant horizontal earth-currents, as observed at the Ebro Observatory, flow, on the average for the year, in the direction from about 29° west of North to 29° east of South, or, approximately, in the direction from the Magnetic North Pole towards south-southeast (paragraph 11). The average value, for the magnetically-calm days during 1914–1918, of the potential gradient of the component of the current flowing from true North to South was 0.20 volt per kilometer, and that of the component towards geographic East was 0.11 volt per kilometer, or about one-half of the north-south component. The resultant horizontal potential-gradient was 0.23 volt per kilometer, which during electric or magnetic storms may reach a value 0.8 to 1.0 volt per kilometer (paragraphs 10, 11, and 15).

b. The annual variations of the earth-current potential-gradients and of the components of the Earth's magnetism, as observed at the Ebro Observatory, may be related to one another as cause and effect only to a very minor extent; both sets of variations may have to be referred, more or less, to common causes. (Paragraph 18). The range of the annual variation of the north-south electric component is about 2.5 times that of the west-east component. (Table 6; Fig. 1.)

c. The diurnal variation of earth currents as observed at the Ebro Observatory along lines somewhat over one kilometer long is remarkably similar to that observed at Berlin along telegraph lines, 120 and 262 kilometers in length, from 1884–1887 (Tables 8 and 9, and paragraph 25; Fig. 9). In both cases the diurnal variations for the component of the current along the meridian is considerably more pronounced (2–3 times) than that along the parallel of latitude. The diurnal variation in the north component of the

Earth's magnetism is not such as to correspond to the direct magnetic effect of the diurnal variation of the west-east component of the earth currents. A similar conclusion had to be reached with regard to the east component of the Earth's magnetism and the north-south component of the earth currents. The general conclusion was that the north-south earth-current might be the result of electro-magnetic induction, caused by the fluctuation during the day of the west-east component of the Earth's magnetism (Paragraph 22; Figs. 2 and 3). If it be recalled that all analyses of the diurnal variation field of the Earth's magnetism have shown that the magnetic diurnal variation is in part to be ascribed to electric currents circulating in the regions overhead and in part to currents circulating within the Earth's crust, exact agreements between magnetic variations and earth-current variations are not to be expected. It further remains to point out that until we have some knowledge of the actual course or distribution of the earth currents in the Earth's crust and as to how the conductivity of the crust may vary with temperature and other meteorological causes during the day and at the actual place of observation, attempts to find a quantitative relationship between terrestrial-magnetic and earth-electric effects may be futile.

d. The horizontal vector-diagrams both for the magnetic and earth-electric components vary during the sun-spot cycle in about the same proportion. The earth-current vector-diagram is symmetrical about a line approximately in the direction of the Magnetic North Pole. (See Paragraph 24; Figs. 5 and 7.)

e. The extreme diurnal range of the Ebro earth currents reaches its highest values near the equinoctial months, and lowest near the solstitial months. Earth currents, atmospheric electricity, the Aurora Borealis, and the Earth's magnetic disturbances, all show similar annual variations in the ranges of their fluctuations (Paragraphs 30–33; Fig. 10).

f. The potential gradients of earth currents and of atmospheric electricity apparently vary during the sun-spot cycle, the former decreasing in the direction of normal flow of current, and the latter increasing with increased sun-spot activity (Paragraphs 35 and 39). The diurnal ranges of the potential gradients of earth currents, as well as of atmospheric electricity, just as is the case for the diurnal variation of terrestrial magnetism, increase with increased sun-spot activity (Paragraphs 30 and 39).

g. There is evidence of a similar six-hour wave in atmospheric electricity, earth currents and terrestrial magnetism (Paragraph 39).

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON.

NOTE ON A SIMPLE MEASURE OF THE EARTH'S DAILY MAGNETIC ACTIVITY.

By Louis A. Bauer.

In a timely paper[1] for the Rome meeting of the International Section of Terrestrial Magnetism and Electricity, Dr. G. van Dijk, of the De Bilt Observatory, makes a very desirable comparison, chiefly for the year 1915, of measures of terrestrial magnetic activity proposed by various investigators. For the various measures, designated below, the following symbols are used here: *D*, magnetic declination; *H*, horizontal intensity; *Z*, vertical intensity; *R*, absolute diurnal range, or difference between extreme daily values of element considered; and *A*, diurnal range of hourly values (mean value over 60-minute interval).

Quantity	Proposer and Institution	Designation
$A^x_h + A^h_d = A^x_d$	Bidlingmaier, Wilhelmshaven Observatory	Bi.
$\frac{1}{100}\Sigma(R^2_D + R^2_H + R^2_Z) = \Sigma R^2$	Chree, Kew Observatory	Ch.
$\Sigma(A_D + A_H + A_Z) = \Sigma A$	Schmidt, Potsdam Observatory	Sh.
$\Sigma(R_D + R_H + R_Z) = \Sigma R$	van Dijk, De Bilt Observatory	Di.
$\epsilon . H R_H$	Bauer, Department of Terrestrial Magnetism	Ba.
Σ(Mag. Char. Nos.) = ΣC	Magnetic Commission, International Meteorological Committee	Me.

If at any observatory the diurnal ranges of *D* and *H* are not available, then those of the rectangular components *X* and *Y* are to be used. In the second, third, and fourth measures the *D*-range is to be expressed in gammas, namely, $H R_D$.

Every one must feel indebted to Dr. van Dijk for having published the values of the above measures for each day of 1915, for the De Bilt Observatory, thus facilitating a fair comparison. Table 1 gives the mean monthly values as derived from van Dijk's tables, in which any unessential decimals have been omitted and the following additional columns have been added: SN, final sun-spot numbers according to Wolfer; SD, sun-spot departures or D-measures[2] of solar activity based on SN; and SP, mean daily prominence-

[1] Activity of the Earth's magnetism and magnetic characterization of days, *Ned. Med. Inst.*, No. 102, Utrecht, 1922.

[2] Bauer, L. A., *Terr. Mag.* vol. 26, p. 47.

areas observed at Kodaikanal, India, according to manuscript values courteously supplied by Evershed, October 19, 1921.

Fig. 1 shows the 9 curves based upon the data in Table 1. An inspection immediately shows a pronounced crest in June for all magnetic measures (Curves 2–6), excepting for the character numbers (Curve 9). This June crest in the magnetic curves occurs one month earlier than the crest in the sun-spot curve (No. 1); it, however, occurs in the same month (June) as does the crest in the *D*-measure of solar activity (Curve 7).[3] For Curve 3 (Ch-measure) the peak is most pronounced because of the method of computation in which the *squares* of the ranges of the diurnal variation are used. It may thus happen for this measure, that, as in the case of the Bi-measure, a few days of large disturbance, or

TABLE 1. *Monthly mean measures of daily magnetic activity based on the De Bilt magnetic observations for 1915*

Month	S.N.	Bi	Ch	Sh	Di	Ba	S.D.	S.P.	Me
Jan	*23.0*	*8.1*	*66*	*73*	*110*	*7.9*	*8.3*	4.4	18.6
Feb	42.3	13.6	97	97	142	9.0	23.1	3.9	22.5
Mar	38.8	24.6	163	141	190	13.1	18.4	7.1	**23.8**
Apr	41.3	26.8	156	143	189	12.1	20.4	6.1	21.4
May	33.0	23.1	124	134	171	11.4	26.4	5.6	20.5
Jun	68.8	**53.8**	**361**	**173**	**224**	**16.1**	**49.0**	3.8	21.4
Jul	**71.6**	31.4	*148*	*158*	*190*	13.0	28.1	3.6	*16.5*
Aug	69.6	32.4	158	160	205	13.7	21.8	6.0	21.1
Sep	*49.5*	*29.8*	190	149	203	13.1	*16.9*	4.8	20.6
Oct	**53.5**	**38.4**	288	**159**	**233**	14.6	**19.8**	6.7	27.0
Nov	42.5	32.6	**299**	140	224	**16.1**	11.1	4.4	**28.9**
Dec	34.5	14.5	121	83	132	9.4	10.5	5.2	18.9
Mean	47.4	27.4	181	134	184	12.5	21.2	5.3	21.8
Curve	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

even but one day, may practically control the value of the measure for the entire month. Take, for example, June 17, 1915, when a very severe magnetic disturbance occurred. According to van Dijk's figures, the various measures contribute the following percentages to their respective monthly means: Bi, 44; Ch, 62; Sh, 15; Di, 20; Ba, 21. It is thus seen that "Ch" was affected most by one-day's severe disturbance, and "Sh" least, which is no doubt chiefly due to the fact that in the computation extreme ranges were not used, as in the case of "Di" and "Ba", but *smoothed* ranges, i. e., ranges from the hourly 60-minute means.

The measures "Bi" and "Ch" may also suffer from the fact that they depend on quadratic formulæ; hence, in order to get their mean values for a month, it is necessary to compute the measures for *each* day. For the linear measures, "Sh", "Di", and "Ba", the mean monthly measure may be derived directly from the difference between the monthly mean maximum and minimum values,

[3] See my previous article *Terr. Mag.*, vol. 26, 1921, Fig. V, and explanation, p. 62.

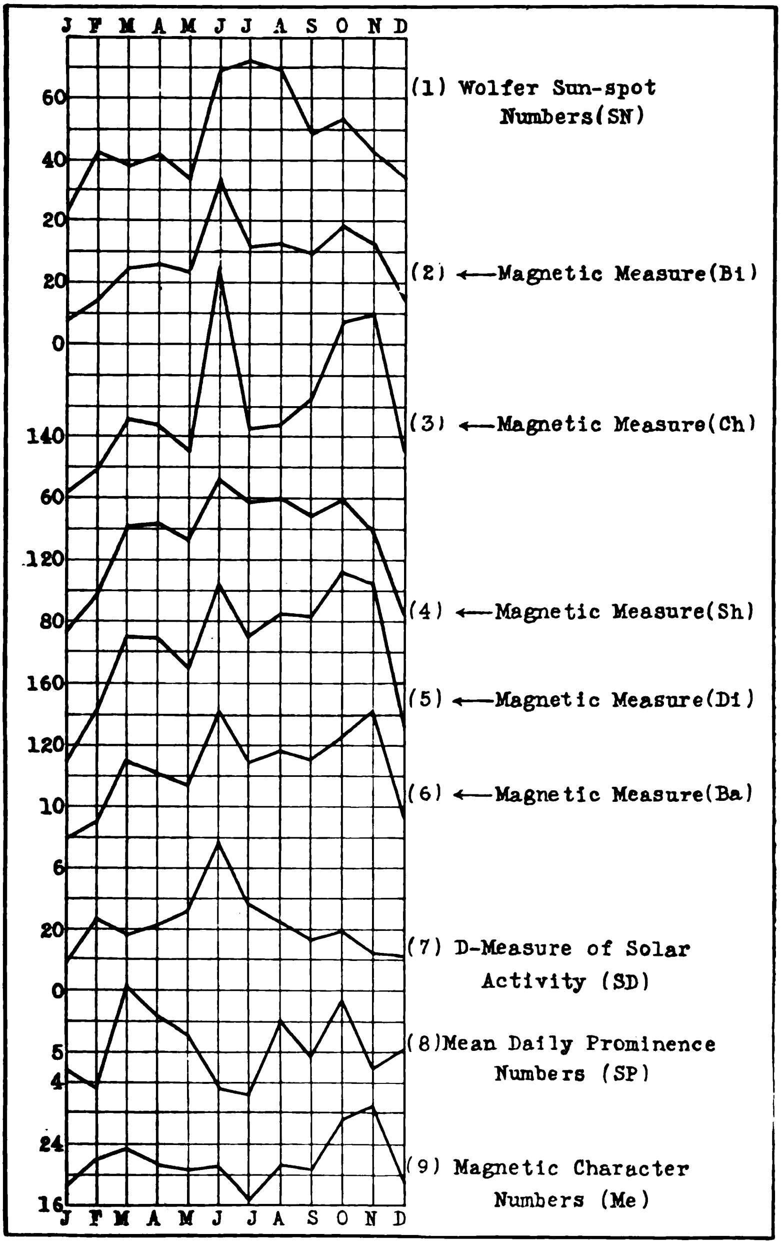


FIG. 1.—Monthly Measures of the Earth's Daily Magnetic Activity for 1915 and the DeBilt Observatory.

and it is, therefore, not necessary to compute the values for each day, unless they are required for some other purpose.

All the magnetic curves (Nos. 2–6) of Fig. 1 show also a pronounced peak, either in October or November, for which no exact counterpart, except to a limited extent, is found in the sun-spot curve (1) and in the D-measure (Curve 7). However, the solar-prominence curve (8) shows a peak in October and the magnetic character numbers, Curve 9, a peak in November; otherwise Curve 9 is the most disappointing one of the magnetic measures, as far as relation with solar activity is concerned. It would appear as though this autumn maximum in the magnetic measures is a striking illustration of an over-developed customary disturbance maximum near the equinoctial months (see also Fig. 10 on page 24 of the present issue of this *Journal*). We have here a class of magnetic disturbances, which cannot be related immediately to sun-spot activity as observed on the disc of the Sun turned at the time towards the Earth. This class must apparently be referred to eruptive matter from solar-prominences and to coronal matter through which the Earth passes in its revolution around the Sun; such cases will be treated at greater length in a future paper.

A further discussion of some of the interesting points raised by van Dijk will have to be postponed at present. It must suffice here to remark that some of the computations made for combined measures, as given, for example, by van Dijk in his Table 5, page 17, I have not advocated for reasons in part stated in paragraphs 23 and 26 of my previous paper[4], and to be more fully set forth in the later paper. When the ranges R_X, R_Y, R_Z, or R_H, and R_Z, must be used instead of the *variations*, dX, dY, dZ, I tentatively restricted my activity measure to $\epsilon\, H\, R_H$. There are two obvious numerical errors in the last column of van Dijk's Table 5, page 17, namely, the quantities for August and November should evidently be 23.59 and 16.09, respectively. If these corrections are made, it will be found that the figures derived from my simple measure in which only the H-range is used and given in the first column of van Dijk's table, follow the same course as those from his extended computations (corrected figures of last column), in which the ranges for the three magnetic components are used.

The limitations of the computing personnel at most of the magnetic observatories require that a measure of magnetic activity be used, preferably of the linear type, which can be readily computed and which will be found to be approximately the same at stations in moderate magnetic latitudes all over the Earth. As already intimated, this matter will be treated at further length in a future communication. Evidently the numbers used at present to characterize the magnetic character of a day require early supplementing in some effective manner.

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON.

April 4, 1922.

[4] *Terr. Mag.*, vol. 26, 1921, pp. 57 and 58.

RESULTS OF MAGNETIC OBSERVATIONS ON THE "MAUD EXPEDITION", 1918–1921.[1]

By H. U. Sverdrup[2] and C. R. Duvall.[3]

Introduction by Roald Amundsen.

In writing a brief introduction to the present publication, I wish to emphasize that the co-operation with the Department of Terrestrial Magnetism of the Carnegie Institution, of Washington, has been of the highest value to the "Maud Expedition." In 1918 the Department of Terrestrial Magnetism made every possible effort to secure for the Expedition, not only the best and most suitable instruments, but also additional equipment which might facilitate the work under the conditions to be encountered. The instruments themselves were successfully modified for use in Arctic regions, and carefully compared with the standards of the Department. The results of the repeated comparisons in 1921 are highly satisfactory, because, according to them the standards of the instruments have remained practically unchanged, thus leaving no doubt as to the reduction of the field observations to the Department's adopted standards.

It must be regarded as very fortunate that the Department of Terrestrial Magnetism found it possible to carry out immediately the computation and reduction of the observations made during the years 1918-1921, and to publish them within eight months after the return of the Expedition, thus preventing them from sharing the fate of so many observations which have not been made available until after many years.

For the future work of the Expedition, it has been of great advantage to have had Dr. H. U. Sverdrup associated with the Department of Terrestrial Magnetism during the past winter at Washington, taking part in the computation of the observations and the comparison of the instruments, which now again are placed at the disposition of the Expedition. The Department of Terrestrial Magnetism has further increased the scientific equipment by the addition of specially designed apparatus for the determination of the atmospheric-electric potential-gradient, and has rendered most valuable assistance in making it possible for the Expedition to obtain instruments for its various researches.

I take great pleasure in availing myself of this opportunity to express my sincere thanks to the Director of the Department of Terrestrial Magnetism, Dr. Louis A. Bauer, and to the Assistant

[1] Full publication will be made in Vol. V, Researches of the Department of Terrestrial Magnetism, Publication 175 of the Carnegie Institution of Washington.

[2] In Charge of the Scientific Work of the Expedition.

[3] Expert Computer, Department of Terrestrial Magnetism.

Director, Mr. J. A. Fleming, under whose supervision, Dr. Bauer informs me, Messrs. Sverdrup and Duvall have prepared the results for publication.

Roald Amundsen

Washington, March 31, 1922.

[The co-operation of the Department of Terrestrial Magnetism with Amundsen's Expedition has proved exceedingly satisfactory and stimulating. Captain Amundsen and Dr. Sverdrup, as well as other members of the Expedition, who participated in the observational work, deserve great credit for the highly successful manner in which their arduous duties under trying conditions were carried out. We confidently look forward to equally successful and valuable results from the future expedition, and wish it godspeed and the best of luck.—LOUIS A. BAUER.]

INSTRUMENTS AND EQUIPMENT.

As the result of a conference at Washington in April, 1918, between Captain Roald Amundsen, Dr. Fridtjof Nansen, and Dr. Louis A. Bauer, certain minor modifications were decided upon in the instruments to be supplied by the Department of Terrestrial Magnetism for the magnetic observations to be undertaken, in co-operation with the Department, on Captain Amundsen's proposed "Maud Expedition" to the Arctic regions. These modifications, none of which altered the intrinsic design of the instruments, were based upon the considerations resulting particularly from the Arctic experiences of Dr. Nansen, Captain Amundsen, and Mr. Peters of the Department. C. I. W. magnetometer, No. 8, and Dover dip-circle, No. 205, were selected as instruments most nearly answering the requirements specified by Captain Amundsen.[4] The required modifications of instruments were made under the direction of Mr. Fleming in the instrument-shop of the Department.

The accessory equipment supplied by the Department of Terrestrial Magnetism for the magnetic work included: 3 tripods; one for magnetometer 8, one for dip circle 205, and the third for use in connection with astronomical observations; 3 magnetic observing tents, containing no iron fastenings of any kind; 3 good

[4] *Cf.* Vol. IV, Researches of Department of Terrestrial Magnetism, 1921, p. 8, and Pl. 2 showing the instruments.

watches; miscellaneous tools, materials, etc.; accessories of various kinds; forms for recording magnetic observations of various kinds, together with some forms for astronomical observations and miscellaneous purposes; miscellaneous scientific books; complete instructions for observations with the different instruments and special instructions for magnetic work in the Arctic.

In addition to the instruments loaned by the Department of Terrestrial Magnetism, the Expedition had also Dover land dip-circle, No. 154, with one pair of dip needles (Nos. 1 and 2), and a photographic registering declinometer, made by Max Toepfer and Son, Potsdam. Registering magnetic instruments were generally not included in the equipment of the Expedition, because in the drifting ice it would not be possible to use them on account of the perpetual movements of the ice, but this declinometer, which was the property of the Expedition, was taken along in the expectation that it might be used at occasional shore stations, e. g., at winter quarters (see page 38).

For astronomical work the Expedition had 3 sextants, 5 theodolites of different sizes, 3 chronometers, and 15 watches (inclusive of 3 supplied by the Department of Terrestrial Magnetism).

METHODS OF OBSERVING.

The magnetic observations were made in accordance with the instructions supplied by the Department of Terrestrial Magnetism. The methods used are given in detail in Volumes I, II, and IV of the *Researches* of the Department (see particularly pp. 13-41, and specimen observations, Vol. I). The experiences encountered by the observers of the Expedition while making magnetic observations in the Arctic do not differ essentially from those of observers on former expeditions; however, they will be found in the fuller publication.

Observatory Work.—At the end of September, 1918, a magnetic observatory was built on shore at winter quarters (Station No. 4). It was built of drift-wood logs and planks, with wooden or copper nails, and was, therefore, perfectly non-magnetic. To keep the temperature as high as possible, the inside was lined with canvas, and snow was thrown over the house. Because of the insulating power of the snow, the temperature in the observatory only accasionally sank below —25° C, while outdoors it might be as cold as about —40° for weeks at a time. The dimensions of the observatory were 3 by 4 meters, and the height, to the ridge-pole, 2.8 meters. In the room two wooden piers were placed at a distance

apart of 1.8 meters. They were driven as far down in the ground as the frost permitted, and had no connection with the floor. The magnetometer was placed on the front pier, and the dip circle on the back pier. During observations, all magnets not in use were placed on a snow pillar 10 meters in front of the house. Both instruments were permanently installed by the end of November.

During the winter, the observatory was lighted by a gaslight lamp of the "Lux" pattern, which also devèlops considerable heat, all iron parts of the lamp having been removed, and replaced with parts of copper or brass. The vernier readings were made by means of small electric lamps, the current being supplied by a dry cell battery which had to be taken on board after each observation in order not to get too cold. The same battery was also used for illuminating the mark for declination observations, which was used in the dark season. This mark was simply a small electric lamp which was fastened on top of a stick in front of the observatory, and could be lighted from the inside of the observatory. During the period of daylight, a pole placed in a cairn at about 600 meters distance was used as a mark.

The observatory house was torn down on April 1, 1919, and a square tent, 2 by 2 meters, made of light canvas, was placed on the wooden floor; thus no artificial illumination was needed. At this season the tent had the advantage of being much warmer than the house. Even on a wholly overcast day the temperature inside the tent might be 10° C higher than outside, while on a clear day with sunshine the temperature might be 25° C higher.

Some trouble was anticipated in the behavior of the watches at low temperatures. It was found that some of the watches, perhaps on account of the quality of the oil used in them, behaved very satisfactorily despite the great changes in temperature.

That magnetic disturbances often caused difficulties need hardly be mentioned. Sometimes the disturbances were so violent that the observations had to be broken off because the magnet disappeared from the field of view time after time.

During the winter of 1918–1919, the photographic declinometer was mounted in a long, low building attached to the observatory, from which it could be entered. The whole building was buried in snow, so the temperature did not sink below —20° C in the registering room. In spite of this, it was not possible at first to make the clock which drives the drum work properly, but this difficulty was overcome by removing all oil by means of a benzine bath and then applying a small quantity of kerosene as lubricant. The registra-

tions were kept up from November 10, 1918, to July 31, 1919, with only occasional interruptions, but, unfortunately, the traces, together with all meteorological and tidal registrations, have been lost (see page 49).

Field Work.—The general experience on this Expedition was that magnetic field work in the Arctic can only be carried out successfully in spring and summer. In the fall and in the winter much bad weather and short daylight make it almost impossible to take magnetic observations in the field, even though it is feasible to travel in these seasons.

The kinds of instruments which may be used in the field depend upon the means of transportation. If the observer travels with reindeer, an ordinary field equipment, including an observing tent, may be taken along, so the conditions in the favorable seasons will be the same as for ordinary field work. But for travel with dog sledges the conditions are different and ordinarily the weight of equipment carried has to be reduced as much as possible. The most suitable instrument for carrying on a dog sledge is the dip circle with compass attachment, but without tripod.

In the spring of 1919 a special program was decided upon to insure obtaining approximately simultaneous observations at field stations and at the winter-quarters station. This scheme was carried out for the work in 1919, but could not be kept up in the two following years: in 1920 all instruments were used for field work, and in 1921 there was a lack of observers.

It will be noted from Table 1 that no declinations were determined at most of the field stations. This was because Messrs. Wisting and Hanssen were unfamiliar with use of the theodolite for determination of azimuth. During January, 1922, the peep-sights of the compass attachment were modified in the instrument shop of the Department of Terrestrial Magnetism in such a way that it will be possible to sight the Sun directly, or to use a shadow-method for determination of azimuth in future work. If, in addition, a sextant observation for local time is made, the true azimuth of the Sun may be computed, and thus all necessary data for determination of the declination will be available.

INSTRUMENTAL CONSTANTS AND REDUCTIONS TO STANDARD INSTRUMENTS.

The instrumental constants and corrections for the various magnetic instruments depend chiefly upon observations at Washington, before and after the field work, and, in part, upon the observers' intercomparisons in the field.

The International Magnetic Standards (designated I. M. S.), as defined in Volume II of the "Researches of the Department of Terrestrial Magnetism", pages 211 to 278 (see also Volume IV, pp. 395–475), have been adopted for the results given in Table 1.

EXPLANATORY REMARKS FOR TABLE 1.

Precisely the same conventions have been followed in the presentation of the field results obtained during the four years 1918 to 1921, as adopted in Volumes I, II, and IV, of the "Researches of the Department of Terrestrial Magnetism". These conventions, briefly recapitulated, are as given in the following paragraphs:

It has not been deemed advisable to attempt at present to apply corrections to the observed results on account of the numerous variations of the Earth's magnetism, e. g., diurnal variation, secular variation, magnetic perturbations, etc. Instead, it is believed to be better to publish the observed results as obtained, with no corrections applied, except the reductions to the magnetic standards of the Department, as already explained. The reduction to a common epoch will be undertaken by the Department later. It will be noticed, however, that opposite the magnetic elements appearing in the table, the precise date and local mean time are given, thus supplying the required information for reducing the observed values to some mean period. The tabular entries are in the order of decreasing north latitude.

The question whether to give values of horizontal intensity exclusively or values of total intensity was decided in favor of the former.

The intensities are published in C. G. S. units. The fourth decimal may be frequently uncertain by one or more units. It will be noted that the values are given to the fifth decimal, but it should be understood that no claim is made as to the correctness of the last figure; the last figure is retained primarily in order that when all reductions to epoch have been applied on account of the magnetic variations an error of a unit in the fourth decimal, due purely to computation, will not enter.

The headings for the columns of the table are self-explanatory. The following abbreviations have been adopted for the months of the year: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec. For stations near the meridian 180° east of Greenwich the dates are reckoned from that meridian without regard to the International Date Line. Local mean times are expressed to the nearest 0.1 of an hour of each value, and are given according to

TABLE 1.—*Results of Magnetic Observations, 1918–1921, on the "Maud Expedition."*

ASIA.

SIBERIA.

Station	Latitude	Long. East of Gr.	Date	Declination L. M. T.	Declination Value	Inclination L. M. T.	Inclination Value	Hor. Intensity L. M. T.	Hor. Intensity Value
	° ′	° ′		h	° ′	h	° ′	h	c.g.s.
No. 14	78 09 N	106 05	Apr 21, '19	....	....	16.9	85 30.2 N	....	......
No. 15	78 06 N	106 45	Apr 23, 19	....	....	15.5	85 38.6 N	....	......
No. 5	77 42 N	103 55	Apr 4, 21, 19	....	....	16.6 (2)	85 26.3 N	16.6 (2)	.04588
No. 16 (Lockwood Islands)	77 35.5 N	105 29	Jul 15, 19	....	....	16.4 (2)	85 32.1 N	16.4 (2)	.04557
No. 17 (Fram Island)	77 33.8 N	105 43	Jul 17, 19	....	....	16.0 (2)	85 32.6 N	16.0 (2)	.04556
No. 19	77 33.2 N	105 32	Jul 19, 19	....	....	11.4 (2)	85 33.0 N	11.4 (2)	.04534
No. 4 Winter Quarters, 1918-1919	77 32.6 N	105 40	Oct 18	13.1 (8)	26 33.3 E	12.5 (4)	85 33.0 N	13.6 (11)	.04557
			Nov 18	11.1 (2)	26 56.6 E	12.4 (9)	85 30.8 N	13.3 (12)	.04583
			Dec 18	12.9 (37)	26 38.9 E	14.2 (26)	85 30.7 N	13.0 (45)	.04575
			Jan 19	10.7 (23)	26 41.0 E	15.5 (16)	85 32.6 N	14.1 (16)	.04548
			Feb 19	12.4 (13)	26 32.6 E	15.6 (19)	85 31.4 N	15.4 (25)	.04584
			Mar 19	13.3 (9)	26 50.4 E	12.5 (13)	85 34.5 N	13.4 (9)	.04543
			Apr 19	15.4 (20)	26 22.0 E	....	....	15.6 (20)	.04613
			May 19	10.7 (23)	27 09.4 E	....	....	10.9 (19)	.04518
			Jun 19	10.9 (16)	26 57.5 E	....	....	10.8 (16)	.04518
			Jul 19	13.7 (27)	26 22.8 E	....	....	13.7 (27)	.04558
			Aug 19	13.9 (3)	26 39.6 E	....	....	16.0 (2)	.04532
No. 4b Winter Quarters, 1918-1919	77 32.6 N	105 40	Mar 19	....	....	12.4 (14)	85 34.2 N	12.2 (12)	.04523
			Apr 19	....	....	15.4 (8)	85 31.3 N	13.7 (2)	.04534
No. 4c Winter Quarters, 1918-1919	77 32.6 N	105 40	Apr 19	....	....	11.4	85 35.0 N	....	......
			May 19	....	....	11.3 (2)	85 34.8 N	11.3 (2)	.04511
			Jul 19	....	....	12.4 (8)	85 31.5 N	12.4 (8)	.04562
			Aug 19	....	....	15.7	85 32.5 N	15.7	.04543
No. 20	77 32.1 N	105 45	Jul 21, 19	....	....	15.8 (2)	85 30.2 N	15.8 (2)	.04610
No. 6	77 32 N	102 44	Apr 7, 19	....	....	16.7	85 25.5 N	16.7	.04673
No. 18	77 30.2 N	105 34	Jul 18, 19	....	....	16.4 (2)	85 00.0 N	16.4 (2)	.05130
No. 8	77 16 N	101 45	Apr 19, 19	....	....	16.0	85 09.4 N	16.0	.04967
No. 13	77 05 N	106 21	May 24, 19	....	....	10.6	85 24.0 N	10.6	.04712
No. 12	76 43 N	107 03	May 21, 19	....	....	11.1	85 15.5 N	11.1	.04863
No. 9	76 34 N	102 47	May 14, 19	....	....	11.4	84 59.7 N	11.5	.05125
No. 7	76 32 N	101 15	Apr 14, 19	....	....	16.9	85 03.0 N	16.9	.05072
No. 11	76 31 N	106 13	May 20, 19	....	....	11.8	85 15.6 N	11.8	.04856
No. 10	76 05 N	104 11	May 16, 19	....	....	11.4	85 03.5 N	11.4	.05070
No. 3 (Port Dickson)	73 30.2 N	80 26	Sep 2, 3, 18	17.0 (3)	28 43 E	19.4	82 37.7 N	18.6 (3)	.07503
No. 32	70 03 N	171 15	Jun 8, 20	....	....	12.6	78 20.4 N	12.7	.11580
No. 33	69 56 N	170 35	Jun 12, 20	....	....	3.0	78 23.3 N	3.0	.11525
No. 31	69 54 N	173 30	Jun 6, 20	....	....	3.4	78 18.0 N	3.4	.11585
No. 21 (Ayon Island), Winter Quarters, 1919-1920	69 52.5 N	167 43	Oct 29, 19	....	....	11.1	78 20.9 N	11.1	.11583
			Nov 19	....	....	11.5 (3)	78 21.4 N	11.5 (2)	.11590
			Jun 18, 20	....	....	12.0 (2)	78 21.6 N	11.3	.11551
No. 40 (Ayon Island)	69 51.2 N	167 57	Jun 16, 17, 20	16.0 (4)	3 26.5 E	17.9 (2)	78 19.7 N	16.1 (4)	.11627
No 30	69 50 N	176 30	Jun 4, 20	....	....	3.9	78 07.4 N	3.9	.11741
No. 29	69 27 N	178 35	Jun 2, 20	....	....	4.3	77 56.0 N	4.3	.11895
No. 39	69 00.8 N	167 04	May 7, 20	11.5	2 25.5 E	17.1	77 36.1 N	13.7 (2)	.12254
No. 28	68 55 N	179 29	May 31, 20	....	....	6.3	77 30.8 N	6.3	12277
No. 37	68 36.7 N	163 45	Apr 11, 12, 20	12.6 (4)	0 09.4 W	13.3	77 32.4 N	15.0 (2)	.12384
No. 36 (Panteleika)	68 36.1 N	161 55	Apr 1, 2, 20	13.2 (4)	1 16.7 W	17.0 (2)	77 48.7 N	13.3 (4)	.12036
No. 34	68 36 N	166 00	Nov 5, 6, 19	....	....	14.4	77 33.5 N	12.1 (3)	.12301
No. 38	68 34.3 N	165 56	Apr 28, 20	10.2 (2)	1 13.5 E	13.6	77 32.8 N	10.3 (2)	.12389
No. 27	68 18 N	182 20	May 27, 20	....	....	15.4	77 06.1 N	15.4	.12631

ASIA.

SIBERIA—*Concluded.*

Station	Latitude	Long. East of Gr.	Date	Declination L. M. T	Declination Value	Inclination L. M. T.	Inclination Value	Hor. Intensity L. M. T.	Hor. Intensity Value
	°	° ′		h	° ′	h	° ′	h	c.g.s.
No 35	68 13.6 N	164 52	Dec 24,31'19	11.9 (3)	0 45.2 E	....	....	11.8	.12732
			Jan 20	11.6 (5)	0 49.0 E	12.5 (3)	77 09.0 N	11.8 (5)	.12733
			Feb 20	12.1 (7)	0 47.8 E	14.8 (2)	77 10.3 N	13.6 (8)	.12732
			Mar 3 20	11.8 (2)	0 50.3 E	15.0	77 09.0 N	11.8 (2)	.12727
No. 26	67 49 N	184 10	May 25, 20	....	....	12.5	76 40.8 N	12.5	.13047
No. 25	67 15 N	185 20	May 24, 20	....	....	18.3	76 16.5 N	18.3	13450
No. 53 (Pitlekai)	67 06.3 N	186 29	Apr 13, 21	13.6 (2)	15 03 E	13.7	76 26.2 N	13.7	.13213
No. 24	67 01 N	187 45	May 22, 20	....	....	15.4	76 12.9 N	15.4	.13409
No. 41 (Cape Serdze Kamen), Winter Quarters, 1920-1921	66 53.2 N	188 21	Nov 29, 20	....	....	....	....	12.2 (2)	.13394
			Dec 20	....	....	11.8 (3)	76 13.7 N	11.7 (4)	.13394
No. 41b (Cape Serdze Kamen), Winter Quarters, 1920-1921	66 53.0 N	188 21	Jan 21	11.8 (9)	16 35 E	12.3 (4)	76 15.5 N	12.3 (8)	.13351
No. 41c (Cape Serdze Kamen)	66 53.0 N	188 21	Apr 26, 21	15.2 (2)	16 39.2 E	....	....	15.1 (2)	.13344
No. 41d (Cape Serdze Kamen)	66 53.0 N	188 21	Apr 26, 21	15.6 (2)	16 40 E	15.8 (2)	76 16.6 N	15.7 (2)	.13334
No. 23	66 32 N	189 00	May 18, 20	....	....	16.5	76 06.0 N	16.5	.13509
No 51	66 10 N	183 50	Mar 15, 21	12.3	13 29 E	13.0	75 35.7 N	13.0	.13949
No. 22 (Kain-ge-skon)	66 03 N	189 50	Mar 20	....	....	12.9 (4)	75 37.0 N	12.9 (4)	.13930
			Apr 20	....	....	13.0 (5)	75 36.5 N	13.1 (5)	.13931
No. 42 (Kain-ge-skon)	66 03 N	189 50	Feb 4, 21	11.0	17 33 E	12.4	75 40.2 N	12.4	.13819
No. 50	65 39 N	183 06	Mar 13, 21	....	....	7.5	74 56.5 N	7.5	.14476
No. 49 (Mass-kan)	65 31.2 N	181 25	Mar 8, 21	11.6 (2)	10 09 E	11.7	74 59.2 N	11.7	.14460
No. 43 (Yan-dang-ai)	65 30 N	188 55	Feb 9 21	10.3	15 16 E	11.4	75 09.5 N	11.4	.14266
No. 52	65 28 N	185 55	Mar 29, 21	....	....	12.6	75 05.5 N	12.6	.14334
No. 48 (An-ma-la)	65 01.4 N	184 12	Mar 21	13.8 (2)	11 34 E	13.4 (3)	74 15.7 N	13.4 (3)	15092
No. 44 (Jan-da-ken-nut)	64 54 N	187 25	Feb 14, 21	10.5 (2)	16 04 E	10.5	74 40.1 N	10.5	.14772
No. 47	64 50 N	185 25	Feb 23, 21	....	....	12.3	74 26.3 N	12.3	.14905
No. 45 (Nabba-kotta)	64 34 N	187 28	Feb 17, 21	....	....	13.9	74 24.9 N	14.0	.14861
No 46 (Emma Harbor)	64 24 N	186 48	Feb 20, 21	13.9 (2)	14 29 E	13.9	74 13.9 N	13.9	.15040

EUROPE.

RUSSIA.

	° ′	° ′		h	° ′	h	° ′	h	c.g.s.
No. 1 (Vaigach)	69 41.5 N	60 12	Aug 12.13'18	14.4 (3)	20 13.7 E	12.0	78 40.8 N	15.2 (3)	.10901
No. 2 (Khabarowa)	69 39.8 N	60 24	Aug 15. 18	14.2 (3)	19 54.5 E	17.6	78 37.4 N	14.7 (3)	.10920

civil reckoning, being counted from midnight as zero hour continuously through 24 hours; 16^h, for example, means 4 o'clock p. m. The declination and inclination values are, in general, given in degrees, minutes, and tenths of minute of arc. The values of declination resulting from compass observations are given to the nearest minute only, as the results cannot be considered of greater precision than the nearest minute.

In the present condensed table the results of the observations at winter quarters, for example, are not given in detail, as will be

done in the fuller publication; instead, they have been summarized, the numeral in parentheses indicating the number of days on which observations were made for the designated interval.

Besides Captain Amundsen and Dr. Sverdrup, those participating in the observational work were Messrs. H. Hanssen, P. Knudsen, and O. Wisting.

A large part of the original computations was carried out in the field by Dr. Sverdrup. The final computations and revisions were made by the authors with some assistance from Mr. H. W. Fisk, of the Department of Terrestrial Magnetism.[1] Subsequent to our revisions of the results, the data from independent computations of the astronomical observations of 1920, as carried out at the Astronomical Observatory of the University of Christiania under the direction of Professor J. Fr. Schroeter, were received; these results agreed with the original astronomical computations thus serving as an additional check.

DISTRIBUTION AND GEOGRAPHIC POSITIONS OF STATIONS.

Fig. No. 1 shows the route of the *Maud* from Norway to Bering Strait. Figs. Nos. 2, 3, and 4 show the positions of the stations on the Chelyuskin and Chukotsk peninsulas. Three of the stations, Nos. 4, 21, and 41, are close to the winter quarters of the *Maud* during the winters 1918-1919, 1919-1920, and 1920-1921, respectively. For these stations, the latitude has been determined with an accuracy of 0′.1. The values of the longitudes are probably accurate within 2′ of longitude more or less. They have been determined by means of chronometers whose corrections on Greenwich mean time were obtained by time signals before the departure from Norway on July 15, 1918, and on the arrival in Nome on August 4 and 6, 1920, and whose rates had been ascertained by numerous observations at the winter quarters. At station No. 4 the longitude determinations by means of the chronometers were checked by observations of the Moon. At stations Nos. 21 and 41 the agreement between the determinations of the Expedition and the longitudes derived from the chart of the north coast of Siberia, issued by the Russian Department of Marine (Hydrographic Division) in 1914, is a good check. This chart is corrected according to the results from the Russian Hydrographic Expedition to the Arctic Sea by the ice-breakers *Taymyr* and *Vaigach*, in 1911 to 1913, and is very reliable according to the experience of the Expedition.

[1] Dr. Sverdrup was associated with the Department of Terrestrial Magnetism at Washington from October, 1921, to March, 1922.

The positions of stations Nos. 5 to 15 on Chelyuskin Peninsula and Crown Prince Alexei Islands are all derived from sextant observations which have been checked by the dead reckoning kept on the sledge-trips. The latitudes therefore are accurate within less than 1′, but errors in the longitudes, which depend upon the rates of the watches used, may be larger. The longitudes are all computed on the assumption that the adopted value for station No. 4, viz., 105° 40′ E, is correct.

The positions of stations Nos. 16 to 20, in the vicinity of station 4, have been obtained by a simple triangulation.

For stations Nos. 22 to 33, along the north coast of Siberia from Bering Strait to Ayon Island, the positions have been derived from the Russian chart of the coast, which has already been mentioned. On the sledge-trip during which these stations were occupied, a distance-wheel was always used, connected with the sledge. At places which were difficult to identify on the map, the distance, according to the distance-wheel, from the nearest conspicuous point was used to find the position. The positions thus obtained have probably no greater errors than about 1′ in latitude and 3′ to 4′ in longitude.

At stations Nos. 34 to 40, astronomical observations were made by theodolite. The errors in the latitudes, therefore, are not more than 0′.5, but the error in the longitudes may be larger, because the longitudes depend upon watches which were carried in the field for seven and one-half months. However, numerous observations made at the same stations from time to time, at intervals of about six days, show that the one watch which was always carried on the body of the observer kept the rate astonishingly well, so the longitudes are certainly not more than 5′ wrong.

At stations Nos. 42 to 53, the values of latitude and longitude have been partly taken from the Russian map of the coast and partly determined by observations. The positions observed by the Expedition show this map to be reliable along the east coast of the Chukotsk Peninsula, and along the south coast as far as Cape Bering; west of Cape Bering, however, it is inaccurate.

NARRATIVE OF THE EXPEDITION WITH REFERENCE PARTICULARLY TO THE MAGNETIC OBSERVATIONS, 1918–1921.

The "Maud Expedition" left Norway in July, 1918, with a total personnel of ten men. Captain Amundsen's plan was to follow the Russian and Siberian coasts eastward to about 165° east longitude, to penetrate as far north as possible in this longitude, let his vessel,

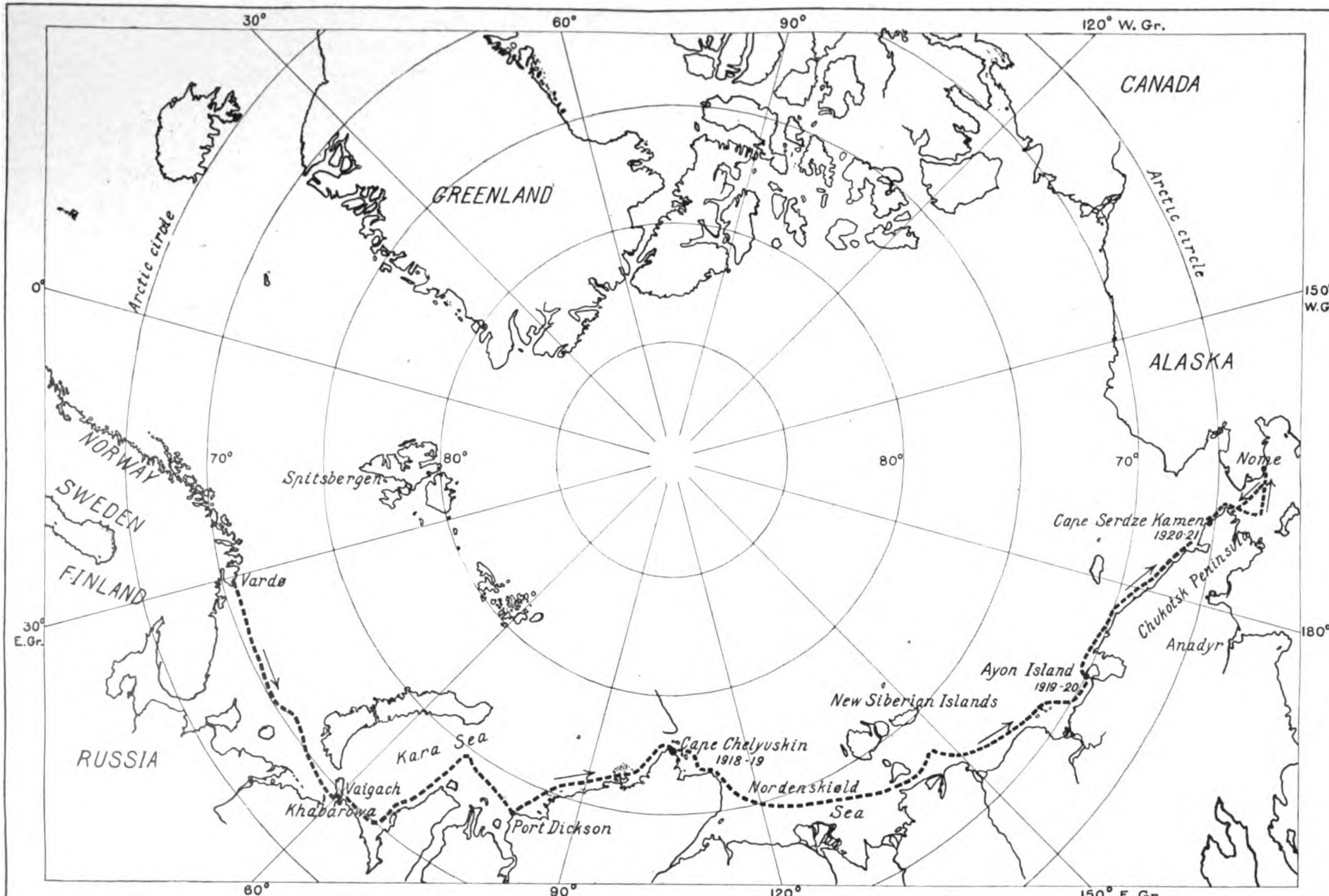


FIG. 1.—Map of Arctic Regions, showing Route and the three Winter-Quarters of the "Maud Expedition," 1918-1921.

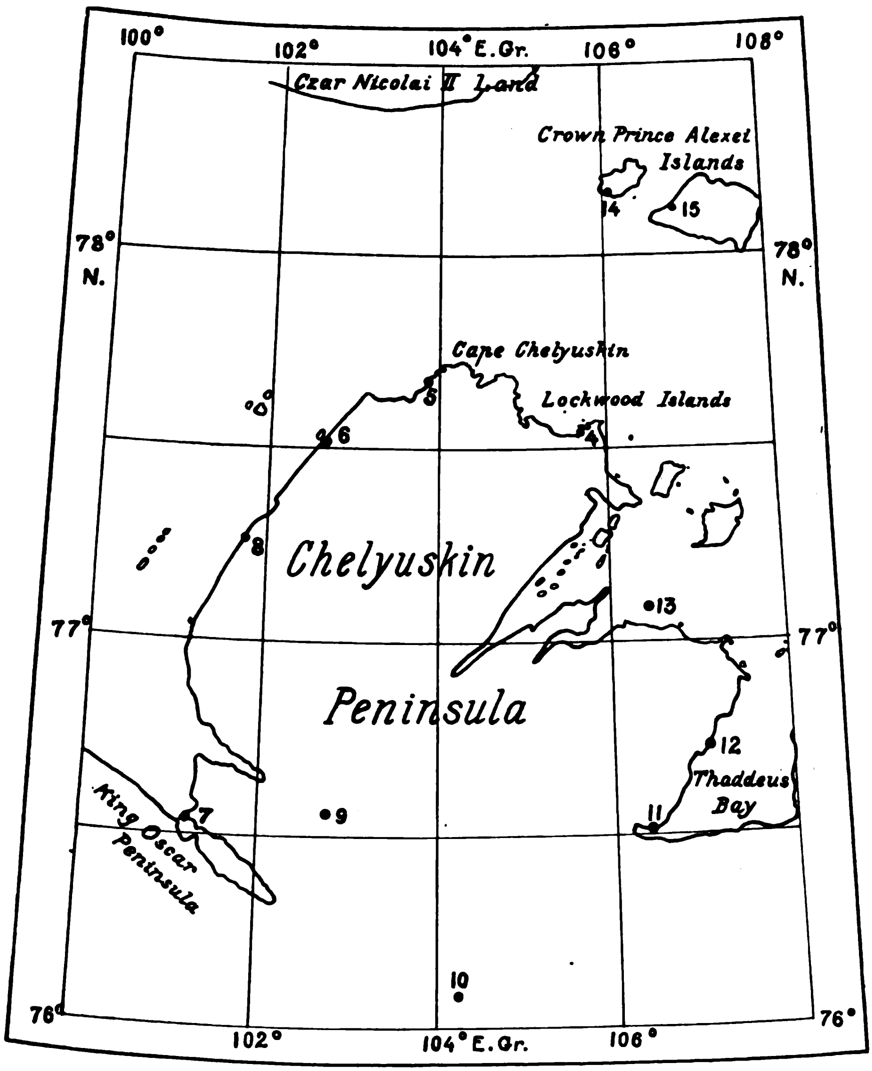


FIG. 2.—Map showing Distribution of Magnetic Stations Nos. 4 to 15 on Chelyuskin Peninsula.

the *Maud*, which was especially built for this expedition, freeze in there, and then let the vessel be carried by the drifting ice across the polar sea until it was released from the grip of the ice between Spitzbergen and Greenland, where the vast ice-masses from the Arctic are drifting slowly south to the Atlantic Ocean. The main object of the Expedition was to study the physical conditions of the Arctic Ocean, but along with the oceanographical work a number of

other observations of interest to geophysics were to be carried out; these included, among others, meteorological, aerological, and magnetic observations. Most of the observations were intrusted to Dr. Sverdrup, but Captain Amundsen himself was to take care of the magnetic observations.

The *Maud* left Vardö, Norway, on July 18, 1918. Ice was met a few days after, but the ice did not form any obstacle worth mentioning before the Jugor Strait, forming the southern entrance to the Kara Sea, was reached. The Strait was filled up with ice, and the *Maud* had to stay at the western entrance until August 17. During this stay two magnetic stations were occupied, one on Vaigach Island at the north side of the Strait, and one at the small Russian trading-place, Khabarowa, at the south side. The last-mentioned station is the one which was occupied by Scott-Hansen on Fridtjof Nansen's north-polar expedition in 1893.

After going through Jugor Strait, the *Maud* met with heavy ice in the Kara Sea and was delayed so much that Dickson Island, north of the Yenisei River, was not reached until August 31. A supply of crude oil was taken on board here, and during this work magnetic observations were carried out. As a steamer with supplies for the wireless station on Dickson Island was expected daily, copies of the magnetic observations were left there, to be sent to the Director of the Department of Terrestrial Magnetism. They were received on January 2, 1919, and the results are published in Volume IV of the "Researches of the Department of Terrestrial Magnetism". (The results are also included in Table 1 of this summary.)

The *Maud* left Dickson Island on September 4, 1918, but again encountered great ice-masses on September 6, west of Nordenskiöld Archipelago. The *Maud* succeeded, however, in passing through the Archipelago, in rounding Cape Chelyuskin, the north point of the continent, and in proceeding about 25 miles further east, but here the progress of the vessel was absolutely stopped by the ice on September 13. There was no harbor, so the *Maud* had to anchor in an open bay about 200 meters from the shore-line. New ice formed rapidly. The *Maud* was frozen fast in a few days, and preparations for the winter had to be made. Although this meant a prolongation of the Expedition for at least one year, it was generally greeted with enthusiasm because wintering here afforded opportunity to carry out a number of investigations in a place hardly touched by former expeditions.

Captain Amundsen selected at once a place for a magnetic observatory close to the shore-line under a small hill. The building was started about September 20, and October 1, it was so far ready that the first observations could be taken in it.

As stated above, it was Captain Amundsen's intention to take the magnetic observations himself, but on September 30, when the magnetic observatory was ready for use, he had the misfortune to fall and break his right arm close to the shoulder. The magnetic

observations up to the end of November were made, therefore, by Dr. Sverdrup, at which time Captain Amundsen was able to take over a part and, later, all of them.

It may be mentioned that systematic observations of the *northern lights* were not carried out because there was no regular night watch. Every display of northern lights between 8 A. M. and 10 P. M. was, however, noted. Only a few photographs of the aurora were taken, mostly as experiments, because it was necessary to save the plates for more northern regions. It may also be mentioned that attempts were made to measure the *potential gradient of the atmospheric-electric field and the conductivity of the air*, but the equipment secured during the war was not satisfactory, the main reason being that satisfactory insulation could not be maintained. The atmospheric-electric observations, therefore, had to be given up.

During April and May, 1919, a number of journeys with dog sledges were planned in order to explore the most northerly peninsula of the continent. Messrs. Hanssen and Wisting were to undertake the longest trips, and they, therefore, received during February and March, instructions from Dr. Sverdrup in taking magnetic observations with the dip circle. Mr. Wisting especially showed himself an able observer, and he was for that reason intrusted with carrying out the magnetic observations on the sledge journeys.

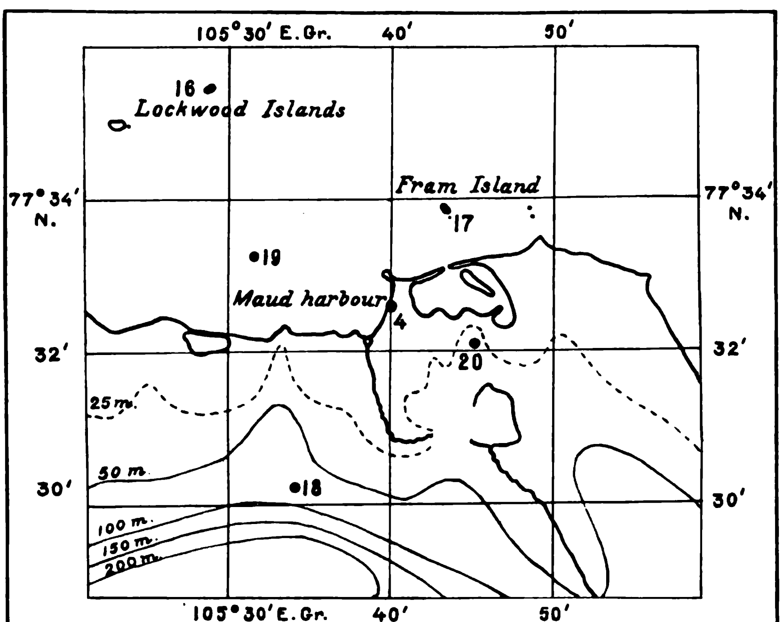
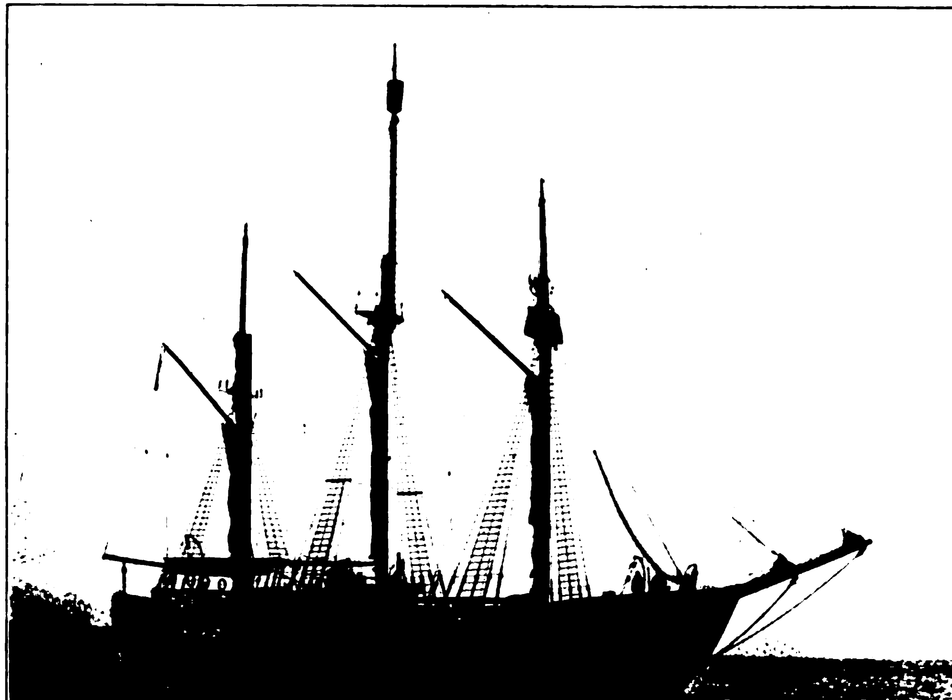
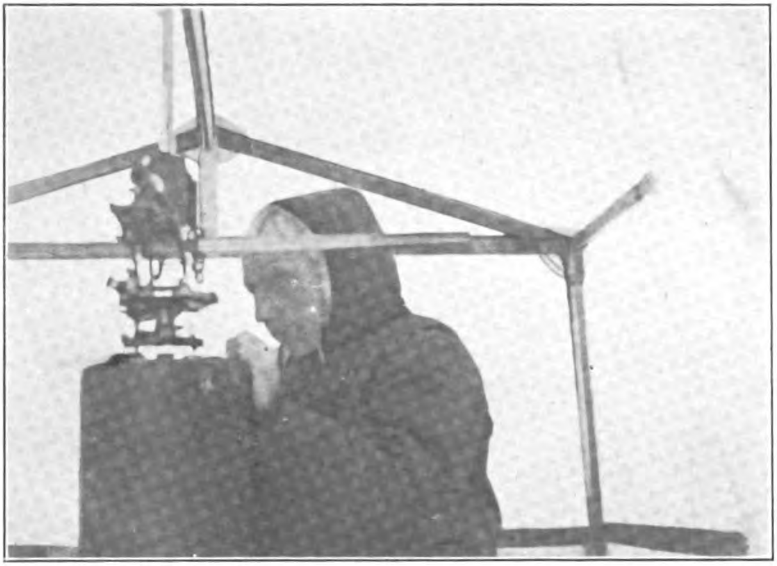


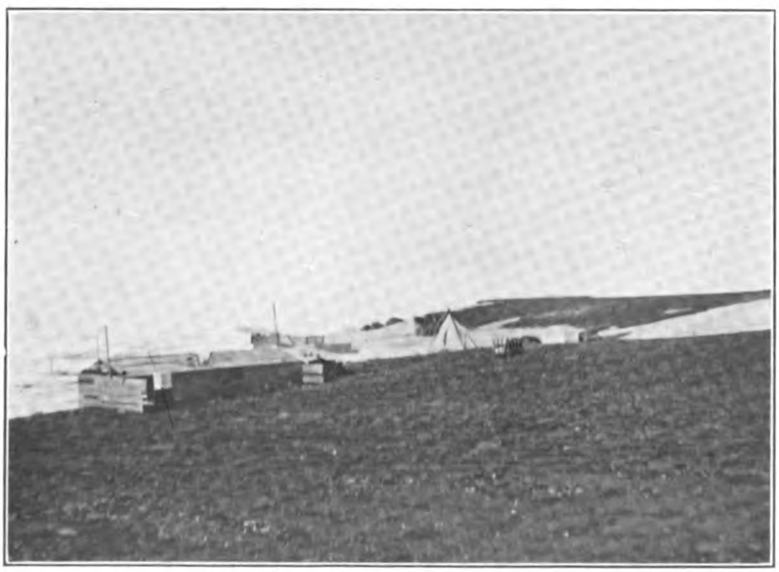
FIG. 3.—Map showing Distribution of Magnetic Stations Nos. 16 to 20 in the Vicinity of Winter-Quarters during 1918 to 1919.



CAPTAIN AMUNDSEN'S ARCTIC SHIP, THE "MAUD."
[Dimensions: Length over all, 120 feet; Beam, 40 feet; Mean Draft, about 15 feet; Registered Tonnage, 297; Machinery, Crude Oil Motor, 240 H. P.; Rig, Three-Masted Schooner.]



1. Captain Amundsen observing with Magnetometer.



2. Winter-Quarters During 1918 to 1919.

Messrs. Hanssen and Wisting were out on two sledge journeys. On the first they were away 23 days, following the coast west and southward for about 150 statute miles and returning the same way. On the second they at first followed their old route, but then crossed overland from the west to the east coast of the peninsula and came back on the 26th day after a round trip of 352 statute miles. Mr. Wisting had then observed at nine stations along the coast or inland, the average distance between the stations being about 45 miles. The observations obtained from the journey in April were taken under very trying conditions, as they had to be carried out in the open air at low temperatures, a snow wall affording the only protection against the wind. Unfortunately the observations comprise only inclination and total intensity and not declination, because neither Mr. Wisting nor Mr. Hanssen was sufficiently familiar with the necessary astronomical observations.

At the end of April a party of four was sent to Crown Prince Alexei Islands lying 40 miles north of the *Maud's* winter quarters. They observed the inclination at two stations with dip circle, No. 154.

Early in the spring of 1919 Captain Amundsen resolved to send home all observations from the first wintering by way of Dickson Island. He hoped that the ice conditions would permit him to start the drift in 1919, and thought it would be best to let two men bring the results of the year's work to civilization as soon as possible, mainly because the observations might get lost if the *Maud* were crushed in the ice. For that reason, in the middle of August, all observations were packed and sewed up in oil cloth. One of the packages containing all original magnetic observations and registrations, information necessary for the computations, maps, and sketches was addressed to the Director of the Department of Terrestrial Magnetism. A notebook was kept on board in which all the magnetic observations were copied. The observations were condensed as much as possible in order to have them all gathered in a small book of practically no weight which might easily be taken along in case the ship had to be abandoned. No copies were made of the registrations, and no attempt had been made to tabulate hourly values from them.

After a hard struggle against the ice, the *Maud* was able to leave the first winter-quarters on September 12, 1919. The two men, Messrs. Tessem and Knudsen, who were going to take the observations back, were left behind. They had built a house on shore, and were equipped with tent, sledge, 5 dogs, provisions and fuel for about one year, rifles, ammunition, maps of the coast, compasses, watch, and theodolite. They were instructed to start, if possible, for Dickson Island in the fall as soon as the ice was trustworthy, but if in their own judgment it was not advisable to go during the fall, then to wait until the next spring. Between Cape Chelyuskin and Dickson Island were three caches with supplies of provisions and fuel laid out in 1915, and the greatest

distance between two caches was only 250 miles. The plan seemed perfectly safe, and, in addition, both men had had considerable experience in arctic traveling and were good hunters. However, since leaving Messrs. Tessem and Knudsen on September 12, 1919, nothing has been heard from them. A searching expedition, sent out in 1920, has not brought final result as to their fate, but it cannot be doubted that they perished. The original copies of the absolute observations and all the original photographic registrations of declination were lost with them. *No copies exist of the photographic registrations, and so they are a total loss, but all absolute observations had been copied.*

It soon became apparent that it would not have been necessary to send Messrs. Tessem and Knudsen home because the *Maud* did not succeed in penetrating into the drifting ice of the polar sea, as hoped. In the vicinity of Cape Chelyuskin and across the Nordenskiöld Sea, the *Maud* met much more ice than earlier expeditions have encountered in the same season, and on the east side of the New Siberian Islands there was only a narrow lead of open water between the heavy pack-ice and the coast. An attempt to penetrate to the north here soon had to be given up, and under these conditions nothing was left but to seek new winter-quarters at the coast. Captain Amundsen resolved to go to Chaun Bay, but when Ayon Island was reached at the entrance of the bay, further progress was absolutely stopped by the ice. A strip of old ice 2 miles broad was found along the coast. The *Maud* was forced in some hundred yards among the old ice-floes, where she stayed perfectly safe during the whole winter.

When the Expedition came to Ayon Island, a number of natives of the Chukchi tribe were living there. These natives were reindeer nomads who spent the winter in the timbered inland, but the summer at the coast. It soon became apparent that they were so primitive, that it would be of interest to learn as much as possible about their customs. For that reason, at Captain Amundsen's suggestion, Dr. Sverdrup went with the natives when they left the the coast and stayed among them for 7½ months until they came back to the coast the following spring. Besides making notes of ethnological interest, Dr. Sverdrup carried out magnetic observations in the inland, using theodolite-magnetometer No. 8, with tripod, Dover dip circle, No. 154, a small astronomical theodolite (Hildebrandt, Freiberg, No. 4474), and an observing tent. The time before the departure was so short and so much had to be done to provide for the different observations which were to be taken on board during the winter, that no time was left for magnetic observations.

It was rather trying to travel with the natives because they moved so slowly. They took two months to cover the 170 miles from the coast to the inland where they stayed during the winter. On the days when they were moving, most of the time till noon was used for preparations, for taking down the tent, lashing the

sledges and catching the reindeer, and then they were able to cover 8 to 10 miles, but generally much less. It often happened, after having spent hours and hours in getting ready, they stopped after the first mile.

In this season conditions were very unfavorable for observations. The daylight was short, and much bad weather made astronomical observations impossible. Observations were made, therefore, at only one station, but no astronomical observations could be secured. From the end of December, 1919, to the beginning of March, 1920, the natives were living in the same place, and magnetic observations were usually secured once a week, but the low temperature in the observing tent sometimes was a hindrance. The observations with the dip circle once had to be interrupted because frost formed so rapidly on the agate bearings for the dip needle that the movement of the needle was not free a moment after it was placed on the agate planes.

At the end of March, 1920, a number of natives were going to the yearly market at the Russian settlement, Panteleika, close to the Kolyma River, to exchange their furs for tobacco and tea. The distance was about 100 miles, and most of the natives did not travel with all their belongings as they did when they moved with their reindeer herd, but they only used their small personal sledges drawn by two reindeer, by means of which they were able to cover the distance in two to three days. Dr. Sverdrup was anxious to go with them, partly in order to see the Russian settlement and partly in order to extend the magnetic observations as far west as possible, but it was difficult to transport the instruments under the circumstances. After some trouble a sledge with two deer was obtained for the instruments, but it was necessary to leave the trunk-cases behind to reduce the weight. The settlement was reached without mishap, and two series of magnetic observations were taken there.

On the way back the reindeer which were pulling the sledge with the instruments were worn out and on the verge of breaking down. A stop was made at a Chukchi tent halfway between Panteleika and the winter station to wait for families who came with tents and all belongings to join the group with which Dr. Sverdrup stayed. The interruption was utilized for magnetic and astronomical observations. The Chukchi group now on the way back to the coast was rejoined by the end of April. Two more stations were then occupied. The conditions were now very favorable for observations; there was continuous daylight and very often brilliant sunshine during the day, the temperature in the tent rising several degrees above the freezing point. Dr. Sverdrup left the natives on May 15, 1920, and traveling by dog sledge, reached the *Maud* on May 17. Magnetic and astronomical observations had been made at 5 stations at an average distance apart of about 50 miles. A station on Ayon Island was occupied in the middle of June.

During Dr. Sverdrup's absence, Mr. Wisting had taken several

observations with dip circle No. 205 on the ice a short distance from the *Maud*. On December 1, 1919, Messrs. Hanssen and Wisting left the vessel with two dog teams. Their instructions were to reach the nearest wireless station either at Nome or Anadyr, to send information about the Expedition, and to secure new equipment of different kinds to be sent to Nome, where Captain Amundsen had decided to call in July, 1920. Among the telegrams which were to be sent was one to the Director of the Department of Terrestrial Magnetism in which Captain Amundsen asked for two pairs of intensity needles for dip circle No. 205, because one pair seemed to have been damaged in some way during the inevitably rough transportation on the sledge journeys at Cape Chelyuskin. Mr. Wisting was also instructed to carry out on this journey magnetic observations along the coast with dip circle No. 205, and to occupy stations at an average distance apart of about 50 miles. The traveling along the coast in the middle of the winter was extremely hard, and Mr. Wisting had the same experience Dr. Sverdrup had, viz., the conditions were very unfavorable for carrying out magnetic observations while traveling in this season. Messrs. Wisting and Hanssen reached Cape Deschnew (East Cape) at the Bering Strait early in February. From here Mr. Hanssen proceeded alone to Anadyr, where, through the courtesy of the Russian officials and officials in the United States, he succeeded in sending the telegrams, including the one to the Director of the Department of Terrestrial Magnetism, who received it on March 29, 1920. In the meantime Mr. Wisting stayed with a trader living in the native village of Kain-ge-skon, at the south entrance to Bering Strait. At this point he took a number of magnetic observations in a snow hut, which he built for that purpose. Mr. Hanssen returned from Anadyr in the middle of May, and together they covered the 700 miles from the Bering Strait to the *Maud* in 28 days. During the last 14 days, traveling was very difficult because the snow had melted on the land and they had to keep on the solid sea-ice. At the mouths of the numerous rivers the sea-ice was often covered with fresh water to a distance of several miles from the shore, and they had to make great detours to avoid the water. In some places it could not be avoided, and they were forced to walk miles in water almost kneedeep. In spite of the short time and the hardships connected with fast traveling, Mr. Wisting carried out his instructions completely. He observed at 11 stations along the coast, the average distance between them being about 60 miles, and he brought the instrument back in perfect condition. However, his observations were, as before, restricted to inclination and total intensity.

The *Maud* left Ayon Island on July 6 and anchored at Nome on July 27, 1920. Here the Expedition learned that no news had been received in Norway about Messrs. Tessem and Knudsen. The copy of the magnetic observations for the winter 1918-1919, together with all original observations for the winter 1919-1920, and

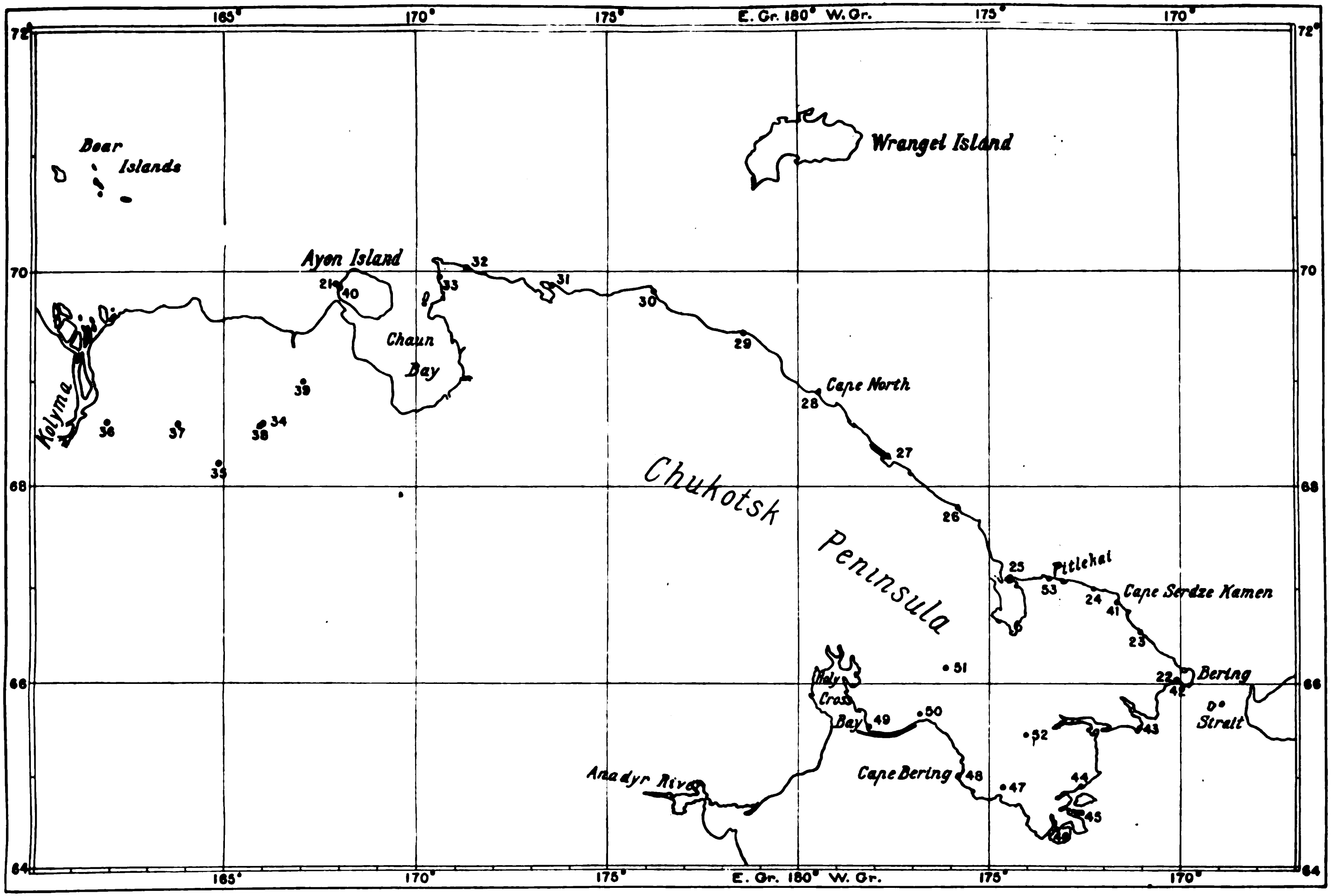


FIG. 4.—Map showing Distribution of Magnetic Stations Nos. 21 to 53 in Northeastern Siberia.
[NOTE: Station No. 28 should be plotted in longitude 179° 29′ E instead of 179° 29′ W.]

copies of astronomical and meteorological observations as far as they were of importance for the computations, were, therefore, sent to the Director of the Department of Terrestrial Magnetism, who received them on September 22, 1920. While at Nome, a package was received from the Department of Terrestrial Magnetism containing two pairs of intensity needles for dip circle No. 205, according to Captain Amundsen's wireless request from Anadyr.

After a short stay, the *Maud* again left for the Arctic on August 8, to make a third attempt to penetrate to the large drifting ice-fields in the north. The attempt failed once more. Even in Bering Strait heavy ice was encountered and it was only with great difficulty that Cape Serdze Kamen, 70 miles west of the Strait, was reached. Further progress was absolutely impossible and accordingly winter quarters for 1920-1921 were established at Cape Serdze Kamen. In the last struggle against the ice the propeller was broken and the shaft was damaged. It was necessary to proceed in the following summer (1921) to Seattle for repairs to the vessel.

Before departing from Nome, the personnel of the Expedition was reduced to four, four having left at Nome because the Expedition would last several years more than anyone thought when the start was made in 1918. This had, of course, an influence upon the scientific work, which also was hampered by the severe weather conditions during the first part of the winter. The ice broke up close to the shore several times in October and November, and it was not before the end of November that the *Maud* was frozen fast. At the end of November a snow hut, where a few observations were made, was built on the shore north of the vessel. Captain Amundsen himself acted as cook and was for that reason prevented from observing. During a severe fourteen-days' snowstorm in the first part of December, the snow hut was buried by the drifting snow and the roof was broken down. Fortunately the instruments had been removed as soon as the storm started. During January, 1921, a number of observations were taken in an observing tent which was set up on a low mound close to the shore west of the *Maud*.

On January 31 Dr. Sverdrup and Mr. Wisting left the *Maud* with two dog teams to follow the coast to Holy Cross Bay, if possible to Anadyr, and on the return to cross overland from Holy Cross to Kolutchin Bay. The objects were to take magnetic observations and to collect information of ethnological interest. The instrumental outfit consisted of dip circle No. 205, theodolite No. 4474, and two watches. The coast followed has a very bad reputation among the traders and the natives, on account of the numerous blizzards; the east and south coasts of the Chukotsk Peninsula are in this respect much worse than the north coast.

The party was away from the *Maud* 69 days and covered 1,200 miles, but on 23 of the days could not proceed on account of blizzards. The attempt to cross overland from Holy Cross Bay to Kolutchin Bay failed. The snow was so deep and soft that the daily travel was very small, and the party had to turn back because

dog feed got scarce. During February and March magnetic observations were made at 11 stations, but on account of the bad weather astronomical observations could be secured at only a few of the stations.

After the return, Dr. Sverdrup took a short trip to Pitlekai, a native village about 50 miles west of the winter quarters, where A. E. Nordenskiöld had taken magnetic observations during the *Vega's* wintering in 1878-1879. A wooden pole driven down in the ground had marked the place of his observations, but according to the natives nothing was now left of this pole. An old woman, who remembered the *Vega*, however, indicated the approximate place where Nordenskiöld's ice-house had stood, and the tent was set up there and a series of observations was taken with dip circle No. 205. The magnetic observations of this winter were closed on April 26, 1921, by simultaneous observations with magnetometer No. 8, and dip circle No. 205, at the station occupied in January, 1921.

The *Maud* left her winter quarters on July 1, and reached Seattle on August 31. It is Captain Amundsen's intention to start out again in 1922 and try once more to get into the drifting ice. The *Maud*, therefore, is being overhauled in Seattle and equipped again for a number of years. During these repairs Dr. Sverdrup took the magnetometer and the two dip circles to Washington where they were compared with the standards of the Department of Terrestrial Magnetism. Dr. Sverdrup reported at Washington in the latter part of October, 1921, and continued there until March, 1922.

(In the summer of 1921, Captain Jacobsen searched the coast northeast of Port Dickson and returned to Norway by way of Petrograd in February, 1922. At Cape Wild, about 250 miles northeast of Port Dickson, where a cache had been left by the "Eclipse" Expedition in 1915, a letter dated November 14, 1919, and signed by Tessem and Knudsen, was found. In this letter was stated that they had arrived in good health at Cape Wild on November 10, 1919, but had found the cache there partly damaged by sea-water, because the waves had, apparently, washed over the point on which the cache was placed. They had moved part of the cache about 25 yards in and had supplemented their own provisions. With supplies for 20 days they proceeded to Port Dickson. On the coast between Cape Wild and Port Dickson, Captain Jacobsen found remnants of several campfires built of driftwood. At the last one, pieces of half-burnt clothing, buttons, and cartridges and other things were found. It has been suggested that one of the two men had died and that his body was burned by his companion, of whom, however, no trace has been found.)

DESCRIPTIONS OF STATIONS.

In general the topography of the regions in the neighborhood of the stations, the absence of prominent marks and buildings, and the

meteorological conditions prevailing made infeasible detailed descriptions such as would permit precise recovery of all the points. Such descriptions as were possible to give will be found in the fuller publication. Any one requiring information regarding location of any station, before the fuller publication appears, should apply to the Director of the Department of Terrestrial Magnetism, Washington, D. C.

SECULAR-VARIATION DATA.

Previous observations of the magnetic elements in the general region covered by the Expedition were made by A. E. Nordenskiöld on the "Vega Expedition", during 1878–79, and by Nansen during the "Norwegian North Polar Expedition" of 1893–96. Table 2 shows the data obtained for the several magnetic elements by previous observers and by the "Maud Expedition", together with the resulting values for mean annual change. It had been hoped also to obtain annual-change values at Cape Chelyuskin, but Nordenskiöld's station at this place was apparently in a locally disturbed area, his value for declination being 129° 09′ east; it was not feasible, therefore, to get any reliable secular-change data by comparing his results with values interpolated for his position from stations occupied on the "Maud Expedition". The data for the "Maud Expedition" values at St. Laurent Bay and Konyam Bay are obtained by interpolation for the first case from values at stations Nos. 42 and 43, and in the second case from values at stations Nos. 44 and 45.

TABLE 2.—*Secular-Variation Data.*

Station	Latitude	Long. East of Gr.	Authority	Date	Declination		Inclination		Hor. Int.	
					Value	Annual Change	Value	Annual Change	Value	Annual Change
	° ′	° ′			° ′	′	° ′	′	c.g.s.	c.g.s.
Port Dickson	73 30 N	80 26	Nordenskiöld	Aug 1878	26 25 E	....	82 55 N	....	.08007	....
			Amundsen....	Sep 1918	28 43 E	3.4 E	82 38 N	0.4 S	.07503	—.00013
Khabarowa..	69 40 N	60 24	Nordenskiöld	Jul 1878	17 07 E	....	....	....	.11558	....
			Nansen......	Aug 1893	....	....	77 38 N	....	.11448	—.00007
			Amundsen....	Aug 1918	19 54 E	4.2 E	78 37 N	2.4 N	.10920	—.00021
Pitlekai.....	67 06 N	186 29	Nordenskiöld..	Mar 1879	19 42 E	....	77 01 N	....	.13188	....
			Amundsen....	Apr 1921	15 03 E	6.6 W	76 26 N	0.8 S	.13213	+.00001
St. Laurent Bay	65 35 N	189 16	Nordenskiöld	Jul 1879	20 24 E	....	75 55 N	....	.14178	....
			Amundsen....	Feb 1921	....	....	75 16 N	0.9 S	.14210	+.00001
Konyam Bay	64 50 N	187 03	Nordenskiöld	Jul 1879	17 52 E	....	75 10 N	....	.14725	....
			Amundsen....	Feb 1921	....	....	74 32 N	0.9 S	.14810	+.00002

PERIODICITY OF ACTIVITY IN TERRESTRIAL MAGNETISM AND THE ROTATION OF THE SUN.[1]

By Dr. G. Angenheister.

The methods by which researches into the physical causes of magnetic storms have been made are essentially as follows:

(I) It has been attempted to determine the geographic distribution of magnetic storms over the Earth. In this way the influence of the Earth's permanent magnetic field, on the geographic arrangement of the disturbance field, has been recognized, and it was made probable that there is an extra-terrestrial cause of disturbance, solar radiation, acting upon this permanent field. We have learned to distinguish several different properties of these storms, such as that some of them are chiefly local in their character, whereas others range over the whole Earth. The known pulsations also belong to the latter.

(II) It has also been sought to determine the velocity of the propagations of disturbances in terrestrial magnetism over the Earth. I believe that, at any rate for the known pulsations, the time-intervals between occurrence of the variations at different stations are smaller than the limits of accuracy attainable with our present means of measurement; certainly they are smaller than 0.1 min. for 10,000 km.

(III) It has been sought to discover a periodicity in these storms by study of their recurrence. There is no doubt that periods of one day, one year, and eleven years have been discovered, which show clearly that the Sun has its influence upon them as a source of disturbance. This is confirmed by a period of the same duration as that of the Sun's rotation.

(IV) It has also been sought to trace the connection between observed phenomena on the Sun and observed occurrences in terrestrial magnetism—to distinguish certain sun-spots as origins of storms. By taking the period between the passage of a given sun-spot across the central meridian and the outbreak of a storm, the velocity of the disturbance in interplanetary space has been computed. Up to the present, this has not been successful. Solar phenomena cannot be identified with disturbances in terrestrial magnetism with certainty sufficient to construct a theory of their relation to one another.

The only success that can be claimed apparently is that the well-known periods in the solar phenomena, such as the eleven-year period, and the rotation have been found in the records of terrestrial magnetism. Still it is hardly possible to regard one as a

[1] Translated by Mr. C. J. Westland, to whom the author expresses his grateful obligations.

function of the other, certainly not with regard to the period of the approximate duration of the Sun's rotation.

It is also noticeable that the data concerning magnetic storms which are supposed to agree with the period of solar rotation appear to vary over wide limits, from about 25 to 30 days. It seems, therefore, not improbable from the preliminary view, that we have to consider the overlapping of several periods connected more or less closely with one another.

In a previous research, I have demonstrated the existence of a 26½-day period in magnetic activity and in the areas of spots and flocculi upon the Sun. A relationship of the two periods to one another in the sense of cause and effect was altogether impossible. It was shown also that at the time of maximum magnetic activity the thickly spotted hemisphere was turned toward us in 1911, while in 1915 the more thinly spotted hemisphere was turned away from us. Beside this 26½-day period there seems to be another of approximately 30 days, especially with respect to the repetition of the greater storms.

In the following, I shall deal at first with some difficulties which we have before us, if we suggest that some of the solar phenomena correspond with the events observed in terrestrial magnetism. We must, in fact, consider that upon the Sun there are certainly various layers which move with different velocities, and in addition to this the rotation period of each layer varies with the latitude. Thus, I shall endeavor to show that in addition to the 26½-day period there is a 30-day period of greater disturbance, and with regard to these I shall show that there is a probable connection with the solar activity which tends to reconcile the contradictory data concerning the 26½-day period in the years 1911 and 1915 stated above.

(A) IS THE VELOCITY OF THE SUN'S ROTATION VARIABLE WITH TIME?

Our knowledge of the Sun's rotation has been obtained from observation of the spots, faculæ, and prominences, which move with the rotation of the earthward side of the Sun, and sometimes last through several rotations. We have additional evidence in the spectroscopic observations of both limbs of the Sun, one advancing and the other receding, in which the comparison of spectra with one another shows the displacement of the lines according to the Doppler effect, from which the velocity of rotation can be determined. Both these methods give approximately the same

results, viz, a synodic period of about 26½ days for heliocentric latitude, 0°, about 28 days for 30°, and about 32 days for 60°. The observations of both methods, however, show discrepancies among themselves, which become greater in accordance with the errors of observation. This is not surprising in observations of spots, faculæ and prominences, as these features undoubtedly have proper motions in longitude and latitude, which tend to give erroneous values of the velocity of rotation. The spectroscopic observations of the Sun's limbs show discrepancies of 12 per cent for the same heliocentric latitude; for example, the equatorial velocity is found to be from 1.86 to 2.11 kilometers per second, and these are less easy to explain. H. H. Plaskett, writing in the *Astrophysical Journal* (1916, p. 145) believes that these varying results really exist. Thus the Sun must have a variable velocity of rotation, which has fallen 5 per cent (from 2.05 km. per second to 1.95 km. per second) during the years 1906 to 1915. The synodic rotation must have lengthened its period from 26½ to 28 days in this time. Again the period must have been ½ day longer in 1915 than in 1913. And yet again the velocity of rotation must have developed a short-period variation of about 7 per cent amplitude (0.15 km. per second) in June and July, 1915. On the contrary, De Lury does not consider these surprising results to be real (*Astrophysical Journal*, 1916, p. 177). His theory is that layers of vapor and dust between the observer and the Sun affect the spectra of the Sun's limbs, so that the observed variation of the displaced lines with time is merely the result of varying amount of dust situated either in the atmosphere of the Sun or in that of the Earth, or possibly in space between them. The light which is emitted from the whole body of the Sun falls on this dust. Then the spectrum of this dust becomes superposed upon that of the Sun's limb, making it more like that of the middle of the disc, and thus it obliterates the displacement of the lines caused by the rotation. Hence the dust seems to diminish the velocity of rotation, which is proportional to the displacement. On days which were free from dust and vapor, he found $v = 1.97$ km. per second; on moist days it was 1.82 km. per second. A moisture of this description would, of course, have considerable effect upon the determination of the solar constant. The measurements of the solar constant must tend to become as free as possible from the errors due to moisture in the atmosphere, by their comparison with one another, and by the choice of stations in localities which are

especially free from moisture. Obviously, they cannot be cleared of the influence of any conditions of moisture in the atmosphere of the Sun or in interplanetary space. If the vapor which causes the magnetic variation of velocity of solar rotation comes from solar activity, a connection between this velocity and the solar activity should be found as the result thereof.

A scale for the solar activity can be found in the relative numbers of sun-spots *R*, in the magnetic character numbers *Ch*, and the value of the solar constant *S*.

Year	V (km.)	U (days)	S (Abbot) (gr. cal. min.)	R	Ch	S (Bigelow)
1906	2.05	26.2	1.956	63	0.646	3.975
1913	1.99	27.1	1.915	1	0.485	4.003
1915	1.95	27.8	1.950	46	0.620	3.990

R and *Ch* show parallel courses. A diagram was drawn showing these in comparison with the velocity of rotation *V*, and the duration of the rotation *U* at the equator; this diagram does not seem to show any such parallelism in the rotation and solar activity. *S* according to Abbot and *S* according to Bigelow run in contrary directions. I have also compared the periodic fluctuation of the velocity of rotation observed in June and July, 1915, with the solar activity derived from the magnetic character numbers. Here a connection seems more probable.

Thus, if at the time of increased solar activity and increased magnetic activity resulting therefrom, the space between Sun and Earth were full of vapor the spectroscopic measurements would suggest a decrease of velocity of rotation, not really existing. The vapor may consist of the Sun's dust, small drops, or swarms of electrons, but the diagram mentioned does not show a sufficiently close coincidence to permit the question to be regarded as decided.

(B) IS THE VELOCITY OF THE SUN'S ROTATION VARIABLE WITH THE HEIGHT OF THE SUN'S ATMOSPHERE?

St. John and Adams, by spectroscopic observations, find different velocities of rotation for different heights of the solar atmosphere. The following table shows the velocities in longitude per day for latitudes 7° and 38°, derived from their measurements of the highest layer of the K_3 line, for the lower layer of the aqueous matter and the comparatively low reversing layer. I have added

the corresponding synodic rotation in days. The velocities stated above then become as follows:

	Sun's Latitude			
	Velocity of Rotation		Duration of Rotation	
	7°	38°	7°	38°
	°	°	days	days
K_2	15.5	15.4	24.7	24.9
H	15.1	14.3	25.5	26.9
Reversing Layer	14.4	13.2	26.7	29.2

De Lury believes that this result may also be rendered fallacious by a superposed spectrum of dust or vapor. On days free from moisture he finds connection between the velocity of rotation and height of atmosphere, but he finds it well marked on damp days. A revision of the results of observation in 1909-1913 leads him to the opposite conclusion which reduces the velocity stated above.

Briefly, it may be stated with reference to the duration of the Sun's rotation: (1) That the spectroscopic measurements themselves show results varying about one or two days for the equator; (2) That it is not certainly decided whether these are real, and (3) that it is also uncertain whether the velocity of rotation varies with the height. Thus it will be difficult to state that any value of the duration of the Sun's rotation, derived from the repetition of magnetic storms, may correspond to any given heliocentric latitude or any given height, wherein we, therefore, should locate the cause of the storm.

(c) TERRESTRIAL MAGNETISM AND SOLAR ROTATION

Adolf Schmidt (*Meteor. Zeitsch.*, 1909) showed that very great magnetic storms are repeated after certain intervals, of which the average value is in round numbers 30 days. Five out of seven of the greatest storms between 1890 and 1909 follow this law. From this it would appear that a definite part of the Sun's surface rotates once in 30 days, and sets in motion new magnetic storms from time to time, frequently after long pauses. All these five storms took place at the time of spot maximum, viz., Oct. 31, 1893; July 20, 1894; Aug. 20, 1894; Feb. 9, 1907, and Sept. 25, 1909 (*Meteor. Zeitsch.*, 1909, p. 509). Adolf Schmidt has recently shown in the Potsdam Annual Report of 1910-11-12-13, repetitions of storms in a single year at intervals of 27½ days.

Other observers find other periods for the return of storms:

Hornstein and Liznar..........	25.87 days	
Maunder (Greenwich).........	27.275 "	(magnetic storms)
Harvey (Toronto).............	27.246 "	
Birkeland (Polar expeditions)...	29.1	
Chree (Kew)..................	27-28	(magnetic character numbers)

These discrepancies in the periods are partly explainable, if we accept the view that spots or faculæ are the causes of the storms, because in the first place spots and faculæ have a proper motion on the Sun's surface which may either delay or accelerate their recurrence in the same position of the Earth, so that a uniform period can hardly be expected; and in the second place, they are situated in different latitudes and have the corresponding differences of rotation-period.

The spots are situated chiefly between latitudes 10° and 35°, the faculæ are also to be found in higher latitudes. Moreover, by taking the mean of longer intervals, we get no constant value for the mean latitude of both spots and faculæ. On the contrary, in the eleven-year period, the mean latitude of the spots moves from 35° at minimum to 10° at minimum, that is, toward the equator, and then at the beginning of the new period, it begins again in 35°. The faculæ, on the other hand, move toward the pole in the same period. Thus, if spots or faculæ are the causes of storms, the repetitions of these storms must give a variable period.

Another cause of uncertainty is introduced into the problem of a definite period, if the Sun's rotation is also variable with time for the same latitude and a stated level, as indicated by the spectroscopic measurements by Plaskett, quoted above.

Many of the observed variations in the time-length of period may be explained in this way. But it will be hardly possible to attribute the 30-day period of the storms, found by Birkeland and Adolf Schmidt, to a similar period of the spots and faculæ. The spots show a synodic revolution of about 26.7 days (at the equator) to 28.0 days (in lat. 30°). Faculæ and calcium flocculi give nearly the same or slightly shorter periods. Thus, if a 30-day period is to be sought, we must have recourse to spots or faculæ which are situated in heliocentric latitude 50°, where they are never, or at least very rarely, seen. Also the cone of rays would require a very wide angle if rays of light emerging in straight lines were to reach the Earth. If we seek the origin of the storms in the zones where the spots and faculæ are situated, i. e., in latitudes 10° to 30°, which has been the usual procedure, then the causes of these storms which repeat

themselves with a 30-day interval can never be situated on the layer where spots and faculæ are formed, because there the rotation-period is too short. If the measurements made by St. John and Adams are reliable in showing the increase of angular velocity of rotation with the height, then the causes of the storms cannot be higher but must be deeper than the spot-layer—deeper than the reversing layer. We should have then the strange physical appearance of a solar atmosphere rotating more rapidly than the nucleus of the Sun. Thus, we must either locate the seat of disturbance at a depth hitherto not investigated, in which layer we accept a duration of rotation previously not observed in these latitudes (10° to 30°); or, as an alternative, we must place the seat of disturbance in those zones of latitude where the required value of 29 to 30 days has been recorded, but where spots and faculæ are seldom to be seen. Moreover, a very wide angle of the cone of rays proceeding in straight lines must be supposed, if the Earth is to intercept such rays.

(D) THE REPETITION OF MAGNETIC STORMS AFTER COMPLETION OF ONE SOLAR ROTATION.

The great discrepancies in the length of the period between the various observed repetitions of the storms encourages the belief that perhaps there are various types of storms which have been utilized in computing the period. Thus there may be: (1) Very great storms of which the sources are situated very deep in the solar atmosphere, and which continue to be active for many years. A duration of rotation amounting to 30 days must be ascribed to this depth of the Sun, and possibly the rotation-period may be constant for this layer in all latitudes of the Sun. (2) Smaller storms which have their sources less deeply situated, possibly just in the reversing layer, and which in such movable material could only maintain a constant duration of rotation for one actual revolution.

This layer has a period of about 26 or 28 days, varying with the latitude. From this point of view, which can be regarded only as a working hypothesis, all the material of the magnetic observations during the years 1906 to 1918, and especially the time of minimum activity 1910 to 1914, was made use of. The international character numbers were found very useful, and also the magnetic observations from tropical stations, especially Batavia, Samoa, and Porto Rico, because of the greater simplicity of the storms in the tropics near the magnetic equator.

(E) THE GREAT STORMS.

From the years of great disturbance—1909-1914—for the present only international character numbers 1.8 to 2.0 were selected from the yearly report. The two great storms which occurred close together on September 25 and 30, 1909, were taken as *initium a quo*. The storm of Sept. 25, 1909, is far the greatest yet observed; it is the last of the five storms in which Adolf Schmidt demonstrated the return after *n* times 30 days. All seventeen storms of character 1.8–2.0, collected from the years 1910-1914, appear then to be repetitions of the two storms of Sept. 25 and 30, 1909, if a period of rotation of 30.0 days is adopted. The dates computed for the repetitions of these storms (accepting this period of rotation) are given in Table 1 for comparison with the observed dates.

TABLE 1.

Series A.				*Series B.*			
Char.	Observed Date	Computed Date	O-C	Char.	Observed Date	Computed Date	O-C
1.8	Sept. 30, 1909	....	.....	2.0	Sept. 25, 1909	....	....
1.9	Mar. 28, 1910	Mar. 29, 1910	—1	1.8	Aug. 22, 1910	Aug. 21, 1910	+1
1.8	Sept. 29, 1910	Sept. 25, 1910	+4	1.9	Mar. 20, 1911	Mar. 19, 1911	+1
1.8	Feb. 21, 1911	Feb. 22, 1911	—1	1.9	Dec. 11, 1911	Dec. 14, 1911	—3
1.8	Aug. 23, 1911	Aug. 21, 1911	+2	1.9	Apr. 9, 1913	Apr. 7, 1913	+2
1.8	Sept. 17, 1912	Sept. 14, 1912	+3	1.8	Jul. 29, 1914	Jul. 31, 1914	—2
1.9	Apr. 6, 1914	Apr. 7, 1914	—1	1.8	Sept. 27, 1914	Sept. 29, 1914	—2
				1.9	Oct. 28, 1914	Oct. 29, 1914	—1

The algebraical mean of the differences: observed—calculated for both series taken together = +0.15 day. It seems from this that in the five years, 1910–1914, two positions upon the Sun have been identified as principal sources of disturbance, and that these have maintained their positions within the Sun unaltered. These are the centers of the disturbances of Sept. 25 and 30, 1909. They lie close beside one another. According to our hypothesis, these centers of disturbance must be considered to be at a depth within the Sun where the duration of rotation amounts to 30 days.

In Table 2 the Series A and B are extended to include several other storms; *n* is used to designate the number of rotations of the Sun of 30 days each—reckoned from the same starting point as the first disturbance. *R* is the period of the rotation computed from two consecutive storms. We extend now our consideration to storms of character 2.0—1.5 during the sun-spot minimum in

1910-1914. If we divide the Sun into two parts, taking a circle of longitude as the boundary line, and keeping the two adjacent storm centers of the series *A* and *B* in the same hemisphere, then this hemisphere supplies 41 out of the 50 storms of character 2.0—1.5. Out of the 37 storms of character 2.0—1.6 during this time, there are 33 from one and 4 from the other half of the Sun.

TABLE 2.

Date	Char.	n	R	Date	Char.	n	R
Jan. 3, 1909	2.0	....	....	Sept. 25, 1909	2.0	....	....
Jan. 31, 1909	1.9	0.93	28.0	Aug. 22, 1910	1.8	11.03	30.1
Sept. 30, 1909	1.8	9.0	30.2	Mar. 20, 1911	1.9	18.03	30.0
Mar. 28, 1910	1.9	14.97	29.8	Dec. 11, 1912	1.9	26.9	29.6
Feb. 21, 1911	1.8	25.93	29.9	Apr. 9, 1913	1.9	43.07	30.3
Aug. 23, 1911	1.8	32.07	30.7	Jul. 29, 1914	1.8	58.93	29.8
Apr. 6, 1914	1.9	63.97	29.9	Sept 27, 1914	1.8	60.93	30.0
Apr. 25, 1916	1.8	88.97	30.0	Oct. 28, 1914	1.9	61.97	31.0
Dec. 16, 1917	2.0	108.97	29.9	Sept. 23, 1915	1.8	72.97	30.0
				Feb. 15, 1917	1.9	90.00	30.1
		Mean	29.8	Aug. 13, 1917	1.9	95.97	29.8
						Mean	30.1

From what has been written above, there can be little doubt as to the real existence of a 30-day period of the greater magnetic storms which took place during the spot minimum of 1910-1914.

It was necessary to make a closer investigation for the time of maximum. For this purpose, the character numbers from 1906 to 1918 were arranged according to 30-day series, beginning at January 11, 1906. In this way it was determined how the various degrees of character from 0 to 2.0 were distributed on the different days of the rotation, and how this distribution altered from the time of maximum activity to that of the minimum. Then it became noticeable that as a rule, two-thirds of the greater character number of a year of maximum is caused by an increase of storms of character 1.2–2.0. It seemed, therefore, especially advisable to make a separate study of these storms of character 1.2–2.0. Accordingly, the two 30-day series 1906–1918 were divided into two halves, one of which covers the time from the 14th to the 28th day of the rotation. Table 3 gives the number per annum of the 1.2–2.0 storms—at the mean times of the 1906–1909 maximum, of the 1910–1914 minimum, and again of the 1915–1918 maximum. Each half is still further divided into 3 parts of 5 days, so that each gives three numbers.

Table 3.—*Yearly average of number of storms of character 1.2—2.0 for a five-day phase interval.*

Rotation Days	A-Half (29-3)	(4-8)	(9-13)	B-Half (14-18)	(19-23)	(24-28)	A-Half	B-Half	A-B
Max. 1906-1909	6.2	9.0	9.0	7.8	5.2	7.8	24.2	20.8	1.16
Min. 1910-1914	6.8	8.0	8.4	3.6	2.6	3.2	23.2	9.4	2.47
Max. 1915-1918	10.0	11.2	12.5	9.0	12.2	9.2	33.7	30.4	1.11

From the figures in Table 3 we see: (1) that for all three intervals of time the A-half gives a larger number of storms than the B-half; (2) that the differences between the halves are very large at minimum, but at maximum very much less marked; (3) that for the A-half the mean yearly number of storms 1.2 to 2.0 is almost equally large for the maximum of 1906–1909 and for the minimum of 1910–1914, so that in the A-half the eleven-year period is very much less sharply defined than in the B-half.

Perhaps these matters stand out more clearly if, instead of the number n of the storms of character ν, 1.2–2.0, we take for comparison the sum $\sum_{\nu=1.2}^{\nu=2.0} n\,\nu$ for five days of the rotation. If we call days of which the character numbers lie between the limits 1.2–2.0 "*disturbed days*", then the numbers $\sum n\,\nu$ of Table 4 become a unit of measurement for the yearly mean of this amount of disturbance for the five-day phase intervals referred to.

Table 4.—*Yearly average of disturbance for a five-day phase interval.*

Rotation Days	A-Half (29-3)	(4-8)	(9-13)	B-Half (14-18)	(19-23)	(24-28)	A-Half	B-Half	A-B
Max. 1906-1907	61	121	121	*144*	103	83	303	330	....
1908-1909	121	*152*	139	81	55	*146*	412	282	....
Min. 1910-1911	145	160	*179*	88	42	52	484	182	2.7
1912-1913	49	*94*	92	20	*40*	33	235	93	2.5
1914	*109*	51	51	25	12	50	211	87	2.4
Max. 1915-1916	125	159	*171*	122	*188*	136	455	446	....
1917-1918	180	*189*	173	131	*173*	136	542	440	....
Max. 1906-1909	91	*132*	130	113	79	*115*	353	307	1.15
Min. 1910-1914	101	102	*107*	44	31	45	310	120	2.6
Max. 1915-1918	152	*174*	172	127	*180*	136	498	443	1.12

Fig. 1.
Spot-Maximum,
1906–1909.

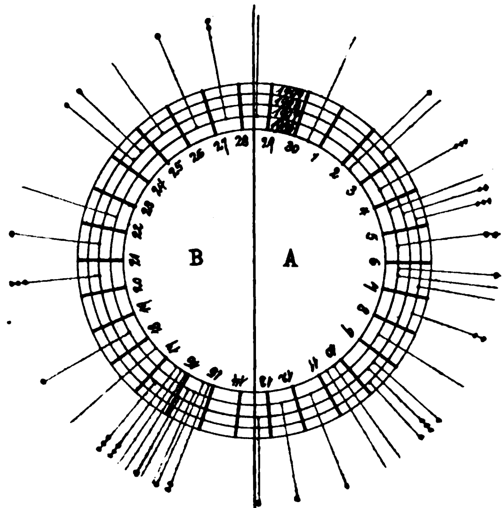


Fig. 2.
Spot-Minimum,
1910–1914.

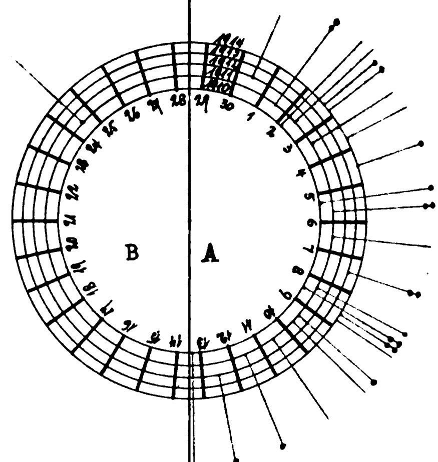
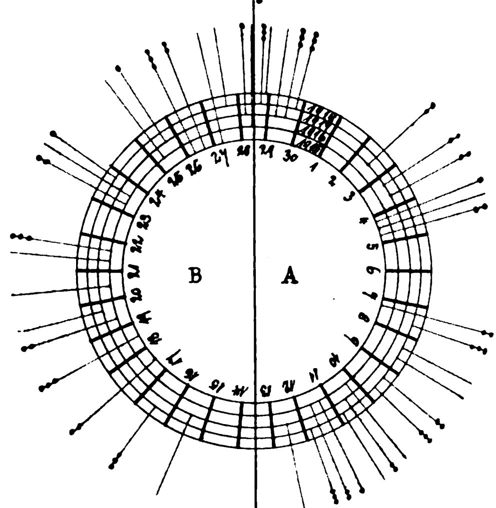


Fig. 3.
Spot-Maximum,
1915–1918.



At the times of maximum 1908–1909 and 1915–1918, both the A- and B-halves have one maximum. The degree of disturbance in the A-half is more strongly marked throughout than that in the B-half.

The contrast between the A- and B-halves, perhaps, comes out even more markedly in the distribution of storms of character 1.5 to 2.0 upon A and B. In the next table the number of storms for each grade, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, is given separately. It is remarkable how similar A and B are to one another, both at the maximum of 1906–1909 and at that of 1915–1918. On the contrary, at the time of minimum the contrast between A and B becomes very pronounced.

TABLE 5.—*Distribution of annual average of the number of storms of character 1.5-2.0 upon A and B.*

		Character Grade						
		1.5	1.6	1.7	1.8	1.9	2.0	1.5–2.0
Max. Time, 1906-1909,	A-Half	1.75	2.30	2.00	1.75	0.75	0.75	9.30
	B "	1.75	1.75	2.00	2.00	0.50	0.75	8.75
Min. Time, 1910-1914,	A "	1.60	1.60	1.60	2.00	1.00	0.00	7.80
	B "	1.00	0.60	0.20	0.00	0.00	0.00	1.80
Max. Time, 1915-1918,	A "	4.00	2.50	1.75	0.75	2.50	1.25	12.75
	B "	4.00	2.00	2.00	1.00	1.25	1.75	12.00

Figs. 1 to 3 show graphically the distribution of the storms of character 1.7 to 2.0 on each individual day of the 30-day periods at maximum and at minimum. If it is true that the Sun is the source of disturbance, then the figures give an illustration of the distribution of such sources upon a Sun rotating in 30 days. Briefly, it may be said on the basis of the above data that the greater magnetic storms (characters 1.2 to 2.0) have a 30-day period, which is shown more conspicuously at minimum.

If the seat of disturbance is situated in the Sun, then in the time of minimum 1910–1914, only the A-half of a layer rotating in 30 days has been found active, whereas at the times of maxima both halves have been equally active. Each half contains then a center of activity, which is almost diametrically opposite to that of the other half. The activity of each center of activity varies

with the time, but each in a different way. The difference between the activity coming from the A-half and that from the B-half is small but appreciable at maximum, but very distinct at minimum (that is, B is inactive).

It appears that at least during the minimum of 1910–1914 the real centers of activity did not cross the boundaries of the A-half: hence they must have their positions constant, at any rate in heliocentric longitude. This proves that they are not situated in the light and movable layer of the flocculi and faculæ, but at greater depths where greater pressure can render certain a more constant position. The 30-day period also gives evidence as to the greater depth of the center of activity. At greater depths, under greater pressure, it is perhaps possible to expect a constant duration of rotation, which according to Adams and St. John must be greater than that of the higher layer, hence, greater than 27 days.

(F) THE SMALL STORMS.

In addition to the 30-day period of those storms which are consistent as to their time-length for the long series of years from 1906 to 1918, there is another far less consistent period of about 27 days to be found among the repetitions of much smaller storms, and this endures mostly for a few cycles only. Within the limits of these shorter cycles, this period often stands out with extraordinary clearness.

At the time of minimum solar activity, the maximum and minimum of the horizontal intensity from day to day show an easily distinguishable period of 27 days—especially at stations in the tropics. This is also the case with the daily mean of the horizontal intensity. The curves of the 24-hourly mean from 6 to 6 hours at Potsdam, Batavia, and Apia, and the curves of the daily maximum and minimum at Apia were tested for this 27-day repetition of storms. Generally, it may be said, especially at the times of increasing activity, there is a good deal that is arbitrary in the selection of the times which may be recognized as the beginnings of a series of repetitions. But in the year 1911 there could be no doubt as to the selection of a point of time where such a series of repetitions commences. Table 6 gives the time-interval between a storm and its next repetition. This rough evaluation already shows practically the same result for all three stations. The close agreement of the mean values is, no doubt, to some extent accidental.

TABLE 6.—*Repetitions of storms, 1911, in days.*

Potsdam	*Batavia*	*Apia*
28	27½	28
27	28	27
26½	26	27
27	26	29
28	28	26
27¼	28	27
26	28½	26
25½	26	26½
27	26½	26½
26½	26½	26½
27½	27¼	28
28	27¼	27
	27	27
	27	
	26	
	26	
Mean 27.0	Mean 27.0	Mean 27.0

The observatories of the United States give in their publications a summary of the principal magnetic storms. The American station situated in the lowest latitude is Porto Rico. The storms are rated 1 to 4, relatively to their magnitude, No. 4 being the strongest. The number of storms of magnitudes 1–4 observed at Porto Rico in the year 1911 amounts to 32, of which 12 are rated 2 and 3, and the remaining 20 are rated 1.

Of these storms there are 12 which may be arranged under Series I of Table 7, and 7 others under Series II. (To Series I one storm, which occurred in Dec., 1910, has been added.) These two series include 19 of the 32 storms of the year 1911, and these are actually 11 out of the 12 strongest storms of grades 3 and 2 included in the two series. Table 7 gives the moment of commencement according to the list published for the Porto Rico Observatory; the differences of time between two consecutive storms is computed therefrom. The means of these differences came to $27^d\ 3^h$ for Series I, and $27^d\ 11^h$ for Series II. The differences vary among themselves between the limits 29 to 26 days. A part of this difference is certainly due to the uncertainty in judging the beginning of a storm. It is seldom possible to say what is the actual commencement of a storm. But the greater part of the difference is dependent on causes which must be sought in the solar phenomena themselves.

The Series I and II follow one another with a mean interval of 7 days. If the character numbers for 1911 be plotted according to rotations of 27 days, the graphs of the two series become two lines of maxima which run parallel to one another at a distance

TABLE 7.—*Magnetic storms in Porto Rico.*

SERIES I

Date	h	Gr'd	Char.	Time Diff.	h
1910 Dec. 28	1	II	1.5	27 Day	0
1911 Jan. 24	1	II	1.7		
				27 "	16
Feb. 20	17	III	1.8		
				27 "	3
Mar. 19	20½	III	1.9		
				26 "	21
Apr. 15	17	II	1.7		
				28 "	19
May 14	12	II	1.6		
				26 "	0
June 9	12	II	1.2		
				26 "	16
Jul. 6	4	I	1.0		
Mean..				27 Day	3h

Date	Char. and period
Aug. 4	0.9 Highest Ch. No. from Jul. 31—Aug. 18
Aug. 31	0.9 Aug. 28—Sep. 11
Sep. 27	0.5 Sep. 24—Oct 1

SERIES II

Date	h	Gr'd	Char.	Time Diff.	h
1911 Jan. 15	1	I	0.9		
				28 Day	18
Feb. 12	19	II	1.2		
				28 "	17
Mar. 13	12	I	0.9		
				25 "	19
Apr. 8	7	III	1.7		
				28 "	5
May 6	12	I	1.4		
				29 "	0
June 4	12	I	1.2		
				26 "	8
June 30	20	I	1.3		
				26 "	16
Jul. 27	12	I	1.6		
				26 "	15
Aug. 23	3	II	1.8		
				27 "	9
Sept. 19	12	II	1.7		
				27 "	17
Oct. 17	5	I	1.4		
				27 "	3
Dec. 10	11	II	1.9		
				27 "	3
Mean..				27 Day	11h

equivalent to a 6- or 7-day interval. In Table 7, the international character number and the amount of disturbance according to the American scale I–IV will be found. Series I shows without interruption first an increase of strength from repetition to repetition, and then a sharp decreasing. In Series II a less regular rise and fall take place. As to the reality of a mean period of 27 days in the repetition of storms, these two series leave hardly any doubt.

In a similar manner, the especially quiet times may be seen recurring at intervals of 27 days, for example, the character numbers arranged according to the 27-day period show this, although the minima naturally are marked less clearly and sharply than the storms.

Chree (*Phil. Trans.*, vol. 213, p. 245) has made a study of the

magnetic character of the days, preceding and following the five most disturbed days of each month, and has found that in the mean (1906–1911 and 1890–1900) the days preceding and following the 27th, 54th, and 81st are more strongly disturbed than any of the others (except the two days immediately preceding and following). Also he found that among the days which precede and follow the quietest days, those before and after the 27th, 54th, and 81st are the quietest in character (also except the two days which immediately precede and follow the starting point).

In order to form an opinion whether this 27-day period is sharply defined, I transcribe a portion of the Table II given by Chree on page 261.

TABLE 8.—*"Character" figures on previous and subsequent days associated with the selected disturbed days of the 11 years, 1890-1900.*

No. of the Day	0	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
"Character" No.																
Preceding Days..	1.51	0.64	0.69	0.68	0.72	0.79	0.90	*0.96*	0.89	0.80	0.73	0.64	0.67	0.63	0.63	0.59
Subsequent Days.	1.51	0.64	0.64	0.63	0.65	0.71	0.83	*0.94*	0.92	0.84	0.79	0.72	0.70	0.67	0.64	0.61

0 signifies the day of disturbance.

The rows show a decided maximum for the 27th day. If only storms of character greater than 1.5 were used, then the years 1906–1911 show a shifting of the maximum to the 28th day.

TABLE 9

No. of the Day	0	25	26	27	28	29	30
Subsequent Character No...	1.68	0.56	0.69	0.82	0.87	0.84	0.75

It seems then that the stronger storms are repeated after rather longer periods, which means that if we accept the Sun as the source of the storms, the position of this source of stronger storms lies in more slowly rotating and therefore deeper layers. The same condition is brought into prominence by the following table. A six-year interval, May, 1909–1915, arranged according to 30-day periods, contained 15 great storms in the first half, that is days 1 to 15 of the rotation, but in the second half, that is, days 16 to 30 of the rotation, there is only one large storm. On the contrary, the smaller storms are distributed much more equally. Out of a total of 48, there are 30 on the first half and 18 on the second half.

TABLE 10.—*Distribution of storms on the individual rotation days.*

30-Day Rotation. (May 25, 1909—May 22, 1915.) Number of Storms.				*27-Day Rotation.* (Dec. 12, 1914—Jul. 2, 1916.) Number of Storms.			
Character No.	1-30 Rot. Day	1-15 Rot. Day	16-30 Rot. Day	Character No.	1-27 Rot. Day	14-20 Rot. Day	21-27-13 Rot. Day
2.0—1.8	16	15	1	2.0—1.8	11	6	5
1.7—1.5	48	30	18	1.7—1.5	26	18	8

A shorter interval—1½ years, from December, 1914 to June, 1916—arranged according to 27-day period, shows quite the reverse distribution. The great storms distribute themselves more equally than the small ones. In this time one center of the Sun is especially active (14–20 day of rotation, almost ¼).

Among the 11 great storms of character 2.0–1.8, there are 6 from this center, while the other 5 are distributed over the remainder of the Sun. Among the 26 smaller storms of character 1.7–1.5, there are on the contrary 18 from this center and only 8 from the remainder of the Sun. If the character numbers be arranged according to the 30-day rotation, then the greater storms are grouped better than the small ones, at least at certain times. But if they be arranged according to the 27-day rotation, then the small storms are grouped better than the great ones. Therefore the great storms have a longer period or their source lies in a layer of the Sun deeper than that of the small storms.

The Series *A* (November 30, 1909) and *B* (Sept. 25, 1909) lead to the same result. All the storms of character 1.8–2.0 may be regarded as repetitions of these two storms. If we take the midway date, Sept. 27, 1909, as the starting point, and let T be the interval between this starting point and the observed days of disturbance throughout the time specified, then T_1, T_2 . . . are almost invariably multiples of 30 days. The mean residual was determined, taking each value from 30 days and disregarding the signs, also the moduli 26, 26.5, and 27 were treated in the same manner.

TABLE 11.

Modulus	26.0	Mean residual	6.3
	26.5		6.5
	27.0		6.2
	30.0		2.8

As these figures show, the mean residuals for the moduli 26, 26.5, and 27 are almost equal to 6.5, 6.6, and 6.75, that is, they are nearly a quarter of the length of the period, which was to be expected. For the modulus 30, on the contrary, it is very much smaller, only 2.8 instead of 7.5. This shows that the dates of the storms are capable of being arranged in periods of 30 days, much more consistently than in those of 26, 26.5, or 27 days.

(G) RECURRENCE OF STORMS AND THE SUN'S ROTATION.

The deduced result then of the investigation up to the present is that the greater storms are experienced at intervals which are multiples of 30 days, and that these series of recurrences endure for a considerable time. But it also shows that the distribution of magnetic disturbances over recurring periods approximately equal to the Sun's rotation of 27 days can only last for a much shorter extent of time, without irregularities entering in. Moreover, this result is equally true as regards the periods of disturbances and of calm, when taken according to this 27-day period. From these considerations, it would be natural to look for the causes of the short-lived 27-day periods, which continue for brief intervals only, in the higher and more variable layer of the Sun, whereas the origin of the more permanent 30-day periods may be sought in the deeper layers. And it may be presumed that these deep-lying centers eject the sources of disturbance into a higher layer which rotates in approximately 27 days, in which they continue to exist for only a few more rotations.

For the present purpose it is immaterial what the physical nature of the storms may be. They may be an electrical radiation similar to the α or β rays coming from certain areas of the Sun's surface, they may be a long coronal streamer reaching to our atmosphere, or they may be a shadow effect caused by a cloud or vapor hanging in the Sun's atmosphere which affects the ionization of the Earth's atmosphere through the normal radiation. Or again, they may be attributed to dust particles, coming from eruptive centers on the Sun, which are driven off by light pressure and penetrate the Earth's atmosphere. The only theory which will be taken for working hypothesis and for demonstration, is that there are centers of activity situated at a considerable depth in the Sun whose activity produces variations from time to time in the less dense layer above (the effects may be either electrical sources of disturbance or clouds).

These variations are the real sources of disturbance, they last only a few rotations, while the centers of activity in the deeper layers last for several years. The lower layer rotates in about 30 days, the higher in about 27 days.

It is not probable that there is any proper motion of these deeper lying and hence not very movable centers of activity in longitude and latitude; these centers must have, therefore, a more constant value for their period of rotation, and after exactly 30 days they should still be found in the same heliocentric latitude and longitude. If the greater storm centers still return after periods which are not exact multiples of 30 days, but which show a retardation of 1 or 2, or even 3 days, then possibly the following explanation may be offered. It is only when the storm center is situated in the same position with reference to the Earth at the first and second of the two consecutive outbreaks, that the time-interval will show an exact multiple of 30 days, for it is only in this case that the cause of disturbance brought by the eruption from the deeper 30-days layer into the higher 27-days layer has been during an equal time-interval in this higher layer in both cases. In all other cases it must be situated for either shorter or longer times in this more rapidly rotating upper layer and must reach the same heliographic longitude for magnetic storms effective at intervals earlier or later than those which are exact multiples of 30 days. The maximum acceleration or retardation may then amount to $30-27=3$ days. As a matter of fact, Table 1 shows only one irregularity exceeding this. Another cause of irregularity may be found, of course, in the fact that during the interval between the eruption in the deeper layer of the Sun and the transit of the active storm center through the effective position toward the Earth, the cause of disturbance (now in the higher layer) may move, owing to its own proper motion.

In this hypothesis, which our experience of the magnetic storms leads us to adopt, we may see a confirmation of the theory mentioned in Section A of this paper and not yet proved—that the velocity of the Sun's rotation increases with the height.

The next question is: *Are these 27-day periods the same every year?*

The following table shows the mean intervals between two corresponding storms belonging to each other, according to a rough consideration of the consecutive 24 hourly means, from 6 to 6 hours, and at Porto Rico according to the figures quoted above.

TABLE 12.

	1905	1907	1908	1910	1911	1912	1913	1915
Batavia	......	......	25.6	......	27.2	......	27.5	......
Apia	......	28.0	26.1	......	27.0	......	......	26.2
Porto Rico	26.8	......	......	......	27.3	26.8	......	......
Potsdam	......	28.1	26.5	27.3	27.2	27.6	......	......

There is no probability of a regular motion to be found in these figures, at least not such as Plaskett found from his spectroscopic measurements for the rotation of the Sun's equator, namely a variation of the synodic period of rotation from 26.3 to 27.7 days. If the origins of the storms share with the sun-spots the changes of position found by Spörer, that is from 30° heliocentric latitude, when the curve begins to rise, to about 10° at the time of next minimum, then the period of the storms-recurrence must be shortened in this time by about 1 day. This again seems not to be supported by Table 12. It is not at all to be expected that the origins of the storms can be sought in these spots.

Here let me point out one contradiction that may be found between the observations and our hypothesis. According to the theory, it might be expected that the center of activity of the lower layer (of 30 days rotation), propelled by an outbreak into the higher layer (of 27 days rotation) has its greatest power to disturb at the beginning and is then constantly decreasing in power from rotation to rotation. In the case of the great storms, the intensity should decrease from one 27 days rotation to the next; and the preceding 27th, 54th, and 81st day should not show any remarkable disturbance. This does happen occasionally, but the general law appears to be that an increased strength of the disturbance from rotation to rotation up to maximum, and then a diminished strength from rotation to rotation is the normal course of events, and Series I shows this clearly. Several other examples of the same thing happening could be given.

Also the result of Chree's investigations shows in the mean of several years that the disturbance of the preceding 81st, 54th, and 27th days increases from rotation to rotation, and then the maximum on the day of the disturbance diminishes in the same manner through the following 27th, 54th, and 81st days. It may, of course, have various causes for increasing and diminishing. The sources of disturbance in the layer which rotates in 27 days may develop at a

steady rate (for instance, cloud formation due to cooling), up to a maximum value, and may then disappear equally gradually. Or another cause might be found in the variation of heliographic latitude of the storm centers, which would bring them to their most efficient positions toward the earth and then equally gradually move out of this position. Or again, the yearly variation of the positions of the axes of rotation and the magnetic axes of Sun and Earth towards one another might produce a consecutive increase and diminution in the strength of the storms. In the last case, the increase and decrease must be capable of being expressed as a function of the season of year. These are all points to which further researches might be devoted, and which might perhaps lead to a modification of our hypothesis.

In a previous research (solar activity, radiation, etc.), it was shown, as has already been mentioned, that spots, faculæ, solar radiation and terrestrial magnetism show a 26- or 27-day period for the duration of the Sun's rotation, but that these three phenomena are sometimes in the same phase, and sometimes in opposite phases. In 1911 the more thinly-spotted hemisphere of the Sun corresponded with higher activity and higher atmospheric temperatures; in 1915 it corresponded with less activity and higher solar radiation, and in 1916 with lower radiation, while minimum activity then occurred about a quarter of a period in advance of the spot minimum. These discordant results in different years make it clear that the periods of spots, radiation, and activity, are not precisely the same, but are slightly different, so that the positions of the extremes move one against the other in time. The materials at my disposal up to the present are not sufficient to determine in this way the difference of these three periods with certainty, and to deduce therefrom the heights of the layers to which these three periods belong.

The observations on which the above suppositions are founded are not by any means sufficiently perfect or continuous. The suppositions have been put forward here because they might be useful to form a more comprehensive working hypothesis which I may here set down as the conclusion of this paper.

Working Hypothesis.—The variations which take place upon the Sun take for us the forms of spots and flocculi, and of fluctuations in the solar radiation, atmospheric temperature and magnetic activity. The spots and flocculi and these other variations may have a common origin, which is situated in a layer beneath the spot-

level, which rotates in 30 days. The seat of common origin varies but little over a period of several years. By eruptions of these centers, variations are caused in the higher layers where the rotation is slower. These variations take place in various layers; in the reversing layer they are seen as spots and faculæ; in higher layers they take the form of sources of fluctuation of the magnetic activity, and in still higher layers they may take the form of clouds, and be the cause of the fluctuations in the solar radiation.

As the faculæ or flocculi, the causes of magnetic activity and the fluctuations of the radiation, participate in the rotation of their respective levels, they all show periodicities dependent upon the rotation periods of their layers. Hence we assume that the higher layers rotate more rapidly; the spots and areas of flocculi have the longer period, the magnetic activity has a shorter period, and perhaps the variations of solar radiation have a shorter period still. As these lengths of period differ from one another, their extremes move one against the other. Consequently, the spot-areas, the activity and radiation are sometimes in phase, sometimes in opposition. The discrepancy as regards length of period may also be caused more or less by the fact that the sources of activity are restricted to latitudes lower than those of the spots and faculæ. The centers of activity in the layer which rotates in 30 days, frequently prove effective after long pauses in their activity. The frequency and intensity of this activity show an eleven-year period. Consequently, the spots, the magnetic activity, and the radiation also follow this eleven yearly fluctuation.

The experience that the 11-year period of sun-spots, magnetic activity, and atmospheric temperature stands out clearly and that the relative positions of their extremes remain constant, although success has not been attained in dealing with these three phenomena singly from case to case, is now capable of a natural explanation. For if we integrate over longer time-intervals, of several rotating periods, the difference in time-lengths of the periods, being of the order of a few days, is not effective, and the parallelism of the three phenomena is apparent. But if, on the contrary, we try to find a definite connection between a given spot and a given magnetic storm, both of which may be the effect of one and the same cause, then the difference in phase, owing to the difference in the time-length of their periods, becomes appreciable in a most disturbing way, especially as this difference in phase may be variable from case to case.

Summary of Conclusions.

(1) The greater magnetic storms, character 1.8–2.0, are repeated after integer multiples of 30 days.

(2) If the character numbers be arranged in periods of 30 days and these periods divided into two halves, *A* and *B*, of 15 days each, then the *A*-half produces all the great storms which occurred during the spot minimum of 1910–1914. In the times of maxima, 1906–1909 and 1915–1918, the *A*-half produces only a very small excess of storms over the number coming from *B*.

(3) The eleven-year period is perceptible in *A* as well as in *B*, but is more strongly marked in *B*. It is possible to attribute the greater storms to different longitudes of a layer of the Sun rotating in 30 days. Then at the time of minimum only one-half of the Sun would contain centers of activity, but at maximum both centers would be found active. The 11-year period is found in both these halves, strong in one, slight in the other.

(4) As shown previously by C. Chree, the distribution of magnetic activity over an interval of time approximately equal to the duration of the Sun's rotation, is repeated in a period of 27 days, and sometimes these repetitions continue without much change over several consecutive rotations. It is possible to attribute the disturbed as well as the quiet days to different heliographic longitudes of a solar layer which rotates in 27 days.

(5) It is probable that the 30-day period in magnetic activity corresponds to a layer more deeply situated in the Sun, and the 27-day period to a higher layer.

(6) In the year 1911 a very clearly marked series of storms (I) began, which followed one another at intervals of 27 days. The strength of these storms increases from rotation to rotation up to a maximum strength, and then diminishes equally regularly and in the same manner from rotation to rotation.

NOTES

1. ***Annual Meetings of the American Geophysical Union and its Sections.*** The American Geophysical Union and its several sections met, March 6-8, 1922, at the offices of the National Research Council, Washington, D. C., to hear reports of committees, to consider the agenda for the meetings in Rome, May, 1922, of the International Geodetic and Geophysical Union, and to elect officers. The meetings were well attended and several of the sections reported gratifying progress in their respective fields. The delegates selected to represent the Union and its sections at the Rome meetings are:

Geodesy, Wm. Bowie, United States Coast and Geodetic Survey, Washington, D. C.; *Seismology*, Harry Fielding Reid, Johns Hopkins University, Baltimore, Md.; *Meteorology*, H. H. Kimball, United States Weather Bureau, Washington, D. C.; *Terrestrial Magnetism and Electricity*, Louis A. Bauer, Carnegie Institution, Washington, D. C.; *Physical Oceanography*, G. W. Littlehales, Hydrographic Office, Washington, D. C.; and *Volcanology*, H. S. Washington, Geophysical Laboratory, Washington, D. C.

The *officers*, beginning July 1, 1922, are:

The Union, Louis A. Bauer (chairman), A. L. Day (vice-chairman), Wm. Bowie (secretary); *Geodesy*, John F. Hayford (chairman), R. L. Faris (vice-chairman), Wm. Bowie (secretary); *Seismology*, W. J. Humphreys (chairman), J. B. Woodworth (vice-chairman), D. L. Hazard (secretary); *Meteorology*, E. H. Bowie (chairman), R. DeC. Ward (vice-chairman), A. J. Henry (secretary); *Terrestrial Magnetism and Electricity*, W. F. G. Swann (chairman), Louis A. Bauer (vice-chairman), J. A. Fleming (secretary); *Physical Oceanography*, J. P. Ault (chairman), G. W. Littlehales (vice-chairman), W. E. Parker (secretary); *Volcanology*, L. H. Adams (chairman), T. A. Jaggar (vice-chairman), R. B. Sosman (secretary); and *Geophysical Chemistry*, H. S. Washington (chairman), Whitman Cross (vice-chairman), R. B. Sosman (secretary).

2. *Institut de Physique du Globe.* The courses and work at the recently established Institut de Physique du Globe of the University of Paris, were inaugurated on November 21, 1921. M. Maurain, director of the Institut, will give lectures on the general physical properties of the Globe; terrestrial magnetism and atmospheric electricity. M. R. Dongier, physicist, will give lectures on the physical properties of the atmosphere; actinometry and optical phenomena. M. Brasier, assistant physicist, will direct the work in the laboratory.

3. *Personalia. Prof. Alfred Angot* has retired as honorary director of the Bureau Central Météorologique of Paris. The Bureau itself has been discontinued and the magnetic work which was previously done by it has been taken over by the *Institut de Physique du Globe* of the University of Paris, which is located provisionally at 176 rue de l' Université. *Victor F. Hess*, technical director of the United States Radium Corporation, has been appointed consulting physicist of the United States Bureau of Mines. *John A. Fleming* was appointed, on January 1, 1922, assistant director for field and administrative work in the De-

partment of Terrestrial Magnetism, in order to afford the director, Dr. Bauer, additional time for investigational work. *N. H. Heck* was appointed in 1921, chief of the division of terrestrial magnetism, United States Coast and Geodetic Survey.

4. *MacMillan Baffin Land Expedition.* The Commissioner of Customs and Excise of Canada has informed us that he received, late in January, a letter from the Special Customs Officer at Port Burwell, dated November 18, 1921. The Special Customs Officer states that he had received information from the the Hudson Bay post manager at Amadjuak that Dr. MacMillan was spending the winter at a place called Nauwatta, about eighty miles north of Cape Dorset, Baffin Land. According to this information, Dr. MacMillan intends to get a supply of gasoline from the Hudson's Bay Co. next summer and return to the United States next summer, if possible.

It was the intention originally to establish winter quarters somewhere along Fury and Hecla Strait, considerably north and west of Nauwatta. The location at Nauwatta is, however, a better one from the scientific point of view since the program of magnetic, atmospheric-electric, and auroral observations can doubtless be more effectively carried out there than at a location in Fury and Hecla Strait, which would be much nearer to the magnetic pole.

5. *Amundsen's Arctic Expedition, 1922.* Captain Roald Amundsen is planning to leave Seattle, where the "Maud" has been undergoing repairs, in June, 1922, and make another attempt to drift across the Polar Sea. The main object of the expedition is the study of the physical conditions of the Arctic Sea by determining depths, temperatures, salinities, and currents. In addition to this oceanographical work, a number of observations of geophysical interest are to be undertaken, namely, magnetic and atmospheric-electric observations to be carried out in cooperation with the Department of Terrestrial Magnetism of the Carnegie Institution of Washington; meteorological observations, which will be extended to the upper air by means of pilot balloons and kites; observations of radiation of heat, including solar radiation during the arctic day, and nocturnal radiation during the arctic night, as well as temperature variations in the ice covering the sea, and polar light observations. Opportunity will also be taken of making pendulum observations for determination of gravity over a sea 2,000 fathoms deep. It is furthermore intended to make use of airplanes for geographical exploration, using the vessel as base. Dr. H. U. Sverdrup, chief scientist, who has been associated with the Department of Terrestrial Magnetism from October, 1921 to March, 1922, left Washington for Seattle on March 31. During two visits to Washington, in January and March, Captain Amundsen concluded arrangements for the scientific work of his expedition, as briefly described above. On March 30 to April 1, he tested out on a trip from New York to Washington and return one of the two airplanes generously supplied by Mr. J. M. Larsen, of New York.

6. *Regarding the Magnetic Observations from the "Gjöa" Expedition.* According to a statement in Norwegian papers, the Norwegian Government has granted a sum necessary for the final preparation for publication of the magnetic observations from the "Gjoa" Expedition, the reduction of which has been recently completed. The publication itself, however, on account of the present high cost of printing, very regrettably will have to be indefinitely postponed.

7. *Roald Amundsen's Nordostpassagen* (*The Northeast Passage.*). Kristiania, Gyldendalske Boghandel, 1921, 467 pp., 33 plates and 5 maps. 25 cm. In July, 1918, Captain Amundsen left Norway on board his new vessel the "Maud", with the intention to follow the coast of Siberia eastward to the vicinity of Bering Strait, proceed thence towards the north, let the vessel freeze in, and drift with the ice fields across the Polar Sea back to the Altantic Ocean. However, the ice conditions forced him to winter three times in different places on the coast of Siberia. In July, 1920, after having wintered twice, Captain Amundsen called at Nome to take on board additional equipment for the drift. At his arrival in Nome, the Northeast Passage had been completed the second time in the direction from the Atlantic to the Pacific Ocean. In his new book, which is a worthy successor to his earlier publications, "The Northwest Passage" and "The South Pole", Captain Amundsen describes the voyage of the "Maud" from Christiania, Norway, to Nome, Alaska. In an entertaining and humorous way he tells about the struggle against the ice along the coast, the life on board during the winterings, bear hunting, dogs, and traveling with dog-teams. Considerable information regarding the progress of the scientific work is included in the text, particularly regarding the magnetic work, in which Captain Amundsen always has taken a great interest. A part of the book entitled "Blandt Rentsjuktsjere og Lamuter" ("Among Deer Chukchis and Lamuts") has been written by H. U. Sverdrup, who, during the winter of 1919–20, spent seven and one-half months alone among the natives to study their habits and customs.

The book, which as yet has only been published in Norwegian, is illustrated by numerous photographs, and accompanied by several maps, which partly represent the result of the survey carried out by members of the Expedition.

8. *The Magnetic Survey Work of the Department of Terrestrial Magnetism, 1922.* The *Carnegie*, since her arrival at Washington last November, has been out of commission and will remain so until the end of the present year. During the period of temporary cessation of the ocean work, special effort will be made to complete certain important land work and to obtain the requisite secular change data by re-occupying previous stations. It is expected that the Department will have six field parties in various parts of the world.

PROPOSED MAGNETIC AND ALLIED OBSERVATIONS DURING THE TOTAL SOLAR ECLIPSE OF SEPTEMBER 21, 1922.

By Louis A. Bauer and J. A. Fleming.

Special magnetic and allied observations will be made at stations inside and outside the shadow belt of the total solar eclipse of September 21, 1922, by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, and by various co-operating magnetic observatories, institutions, and individuals. The distribution of the magnetic observatories within the limits of the eclipse and on both sides of the belt of totality is unusually good, as will be seen from the accompanying map taken from the American Ephemeris and Nautical Almanac for 1922 and on which the positions of these observatories have been indicated. These observatories are: North of the belt of totality, Alibag, Dehra Dun, Kodaikanal, and Toungoo, India; Batavia-Buitenzorg, Java; and Antipolo, Philippines; before beginning of eclipse, Helwan, Egypt; after ending of eclipse, Apia, Samoa; to the south, Port Louis, Mauritius Island; Watheroo, Western Australia; Toolangi, Victoria; and Christchurch, New Zealand. This distribution is all the more fortunate since the greater part of the belt of totality is over ocean areas. The stations of the Department of Terrestrial Magnetism will be probably: (1) Coongoola (or Cunnamulla), Queensland, in the belt of totality; (2) Watheroo Magnetic Observatory, Western Australia, south of the belt of totality; (3) in cooperation with Government Astronomer G. F. Dodwell and Professor Kerr Grant of the University of Adelaide, South Australia, at some point in the belt of totality in central Australia.

The general scheme of work proposed by the Department of Terrestrial Magnetism is as follows:

1. *Simultaneous magnetic observations* of any or all the elements according to the instruments at the observer's disposal, every minute from September 21, 1922, $1^h\ 28^m$ to $8^h\ 02^m$ A. M. Greenwich civil mean time.

(To insure the highest degree of accuracy, the observer should begin work early enough to have everything in complete readiness in proper time. *Past experience has shown it to be essential that the same observer make the readings throughout the entire interval.* If possible, similar observations for the same interval of time as on September 21 should be made on September 20 and 22.)

2. At ***magnetic observatories***, all necessary precautions should be taken to insure that the self-recording instruments will be in good operation not only during the proposed interval, but also for some time before and after, and eye-readings should be taken in addition wherever it is possible and convenient. (*It is recommended that, in general, the magnetograph be run on the usual speed throughout the interval, and that, if a change in recording speed be made, every precaution possible be taken to guard against instrumental changes likely to affect the continuity of the base-line.*)

3. *Atmospheric-electric observations* are desirable to the fullest extent made possible by the available equipment and personnel. Observations of potential gradient are most easily provided for and most conveniently taken; in addition to these, observations (preferably for both signs) of either conductivity or ionic content are also very desirable. Full notes regarding cloud and wind conditions and, if possible, observations for both temperature and relative humidity should accompany the atmospheric-electric observations. These observations should cover the same interval as the magnetic observations. The value of the observations on the day of the eclipse will be greatly increased if similar observations can be made during the same time of day on two or three days before and after the eclipse.

4. *Meteorological observations* in accordance with the observer's equipment should be made at convenient periods (as short as possible) through the interval. It is suggested that, at least, temperature be read every fifth minute (directly after the magnetic reading for that minute).

5. *Observers in the belt of totality* are requested to take the magnetic reading every 30 seconds during the interval, 10 minutes before to 10 minutes after the time of totality, and to read temperature also every 30 seconds, between the magnetic readings.

It is hoped that full reports will be forwarded as soon as possible for publication in the journal of *Terrestrial Magnetism and Atmospheric Electricity*. Those interested are referred to the results of the observations made during the solar eclipse of May 29, 1919, which were published in the December, 1919, and in the June, September, and December, 1920, issues of this journal.

General Circumstances of the Total Solar Eclipse of September 21, 1922.

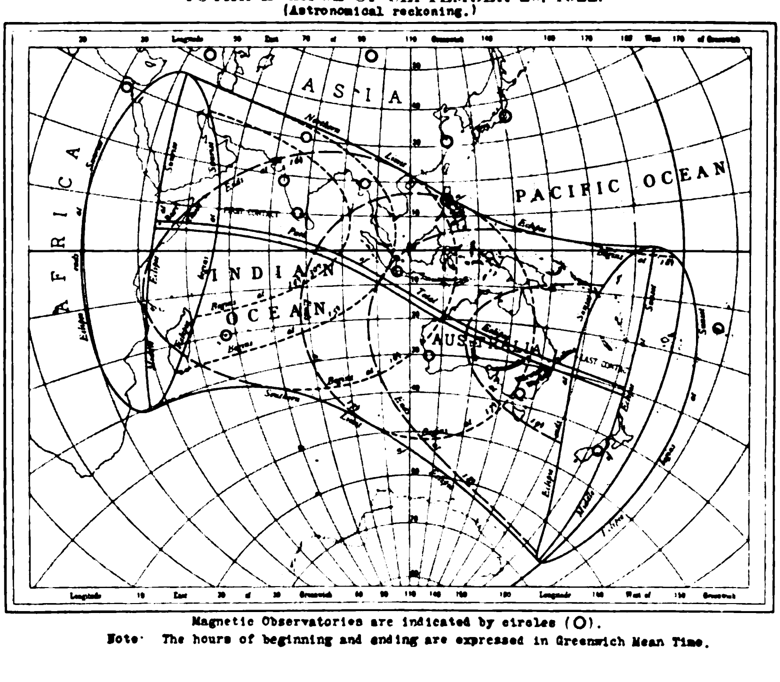
Phase	Greenwich civil mean time			Longitude from Greenwich		Latitude	
	d	h	m	°	′	°	′
Eclipse begins................Sep.	21	2	04.3	57	06 E	9	50 N
Central eclipse begins..........	21	2	59.9	43	17 E	5	30 N
Central eclipse at local apparent noon....................	21	4	47.3	106	31 E	11	59 S
Central eclipse ends...........	21	6	20.6	172	36 E	30	15 S
Eclipse ends..................	21	7	16.2	158	47 E	25	54 S

The following table of approximate local circumstances of the eclipse is abstracted from the report of the Eclipse Committee of the American Astronomical Society published in the October, 1921, number of *Popular Astronomy*.

Approximate Local Circumstances of the Solar Eclipse of September 21, 1922.

Station	Latitude	Longitude E. of Gr.	Civil mean time middle of eclipse		Duration	Sun's altitude
			Gr.	Local		
	° ′	h m s	h m	h m	m s	°
Maldive Islands....	3 N	4 52	3 24	8 16	4 10	34
Christmas Island...	10 25 S	7 02 40	4 47	11 50	3 40	78
Wollal............	19 44 S	8 02 44	5 37	13 40	5 18	58
Coongoola.........	27 45 S	9 44 00	6 17	16 01	3 45	26
Goondiwindi.......	28 30 S	10 01 20	6 20	16 21	3 30	21
Stanthorpe........	28 40 S	10 08 00	6 22	16 30	3 25	19
Casino............	28 50 S	10 12 00	6 22	16 34	3 20	18

TOTAL ECLIPSE OF SEPTEMBER 20, 1922.
(Astronomical reckoning.)



Magnetic Observatories are indicated by circles (O).
Note· The hours of beginning and ending are expressed in Greenwich Mean Time.

ABSTRACT

Bauer, L. A., J. A. Fleming, H. W. Fisk, W. J. Peters, and S. J. Barnett: *Land Magnetic Observations, 1914–1920, and Special Reports.* Researches of the Department of Terrestrial Magnetism, Vol. IV, Publication No. 175, Carnegie Institution of Washington. Washington, 1921, vi + 475 pp., 9 plates, 17 figures. 30 cm.

This volume presents, in continuation of the previous volumes of "Researches" (No. 175, vols. I, II, and III), the results of magnetic observations made by the Department of Terrestrial Magnetism, 1914–1920, and four special reports. The land stations for which the results are reported upon may be summarized as follows: Africa, 447; Asia, 356; Australasia, 315; Europe, 24; North America, 113; South America, 339; Islands of the Atlantic Ocean, 19; Islands of the Indian Ocean, 30; Islands of the Pacific Ocean, 104; the total number of land stations is thus 1,747. The table of results gives names of stations, geographic positions, values of the 3 magnetic elements, dates and local mean times of observations, references to instruments used, and the initials of observers.

Data for the determination of secular-variation have been obtained at 204 C. I. W. repeat localities, the reoccupations for each locality listed involving from 1 to 4 stations. The great majority, 168, of these were either exact reoccupations or close reoccupations (within less than 30 meters). For many of these localities the repeat observations were obtained not only at several stations, but also at different times during 1914 to 1920. In addition to these sources of secular-variation data, fully 150 more of the stations have been practical reoccupations (within less than 300 meters) or proximate reoccupations (within less than 5 kilometers) of stations previously occupied by various exploring expeditions.

The text preceding the table of results gives a discussion of instrumental constants and corrections on adopted International Magnetic Standards as defined on pages 270–278 of Volume II. A brief discussion of the accuracy of the geographic positions is given particularly as regards longitudes. Auxiliary tables to facilitate revisions of field magnetic observations are given, together with graphs for determining without recomputation the corrections necessary in azimuth and time reductions for revised values of latitude or of time.

The volume is concluded with four special reports. "Construction of non-magnetic experiment building," by J. A. Fleming, describes the building specially designed and built for experimental investigations in magnetism. H. W. Fisk discusses "Dip-needle errors arising from minute pivot-defects"; theoretical investigations are made of various cases and illustrated by instructive graphs. "A sine galvanometer for determining in absolute measure the horizontal intensity of the Earth's magnetic field," by S. J. Barnett, describes the design and construction of a new sine galvanometer and gives the theory of the instrument in detail, including the considerations leading to the type of coils used and a discussion of possible sources of error; it is readily possible to make absolute determinations of horizontal intensity with great speed and with an error less

than one part in 10,000, provided the calibrations of the electrical measuring instruments are known with sufficient precision.

The concluding special report by J. A. Fleming on "Results of comparisons of magnetic standards, 1915–1921", is in continuation of the similar report by L. A. Bauer and J. A. Fleming, in Volume II; the results of comparisons obtained at 30 magnetic observatories during 1905 to 1921 are summarized. The provisional "International Magnetic Standards", as previously adopted for the work of the Carnegie Institution of Washington, are found to meet with sufficient precision all theoretical and practical requirements.

LIST OF RECENT PUBLICATIONS

A. Terrestrial Magnetism.

AGINCOURT AND MEANOOK OBSERVATORIES. Results of observations at the Canadian Magnetical Observatories, Agincourt and Meanook. The year 1918. Prepared by W. E. W. Jackson under the supervision of Sir Frederic Stupart. Ottawa, F. A. Acland, 1921 (41 with 12 curves). 29 cm.

AGINCOURT AND MEANCOOK OBSERVATORIES. Magnetic disturbances, November and December, 1921. Toronto, J. R. Astr. Soc. Can., v. 16, No. 2, Feb., 1922 (67), and No. 3, March, 1922 (115).

ANGENHEISTER, G. Anmerkung zur Störung vom 13. bis 16. Mai 1921. Met. Zs., Braunschweig, Bd. 39, Heft 1, Jan. 1922 (20–23).

ANGENHEISTER, G., UND C. J. WESTLAND. Magnetische Störung und Polarlicht vom 13. bis 16. Mai 1921, nach Beobachtungen des Samoa-Observatoriums. Met. Zs., Braunschweig, Bd. 39, Heft 1, Jan. 1922 (19-20).

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VOLUME XXVII NUMBER 3

TERRESTRIAL MAGNETISM

AND

ATMOSPHERIC ELECTRICITY

An International Quarterly Journal

September, 1922

Conducted by

LOUIS A. BAUER

With the Co-operation of Eminent Investigators.

CONTENTS

PUBLISHED FOR
THE JOHNS HOPKINS PRESS, BALTIMORE
THE ABINGDON PRESS, 420 PLUM ST., CINCINNATI, O.
THREE DOLLARS AND FIFTY CENTS A YEAR SINGLE NUMBERS, ONE DOLLAR

WHELDON & WESLEY, Ltd., 28 Essex St., Strand LONDON, W. C., 2

THE ABINGDON PRESS (Cash Subscription) 420 Plum St., CINCINNATI

MAYER & MÜLLER Prinz Louis-Ferdinand Str BERLIN

Entered as second-class matter at the Post-office at Cincinnati

Terrestrial Magnetism *and* *Atmospheric Electricity*

VOLUME XXVII SEPTEMBER, 1922 No. 3

TERRESTRIAL MAGNETISM AND ELECTRICITY AT THE ROME MEETING, MAY, 1922.[1]

GENERAL REPORT BY LOUIS A. BAUER.

The second triennial meetings of the International Astronomical Union and of the International Geodetic and Geophysical Union, established at Brussels in 1919 under the auspices of the International Research Council, were held at Rome, May 2 to 10, 1922, in the quarters of the Accademia de Lyncei, at the Palazzo Corsini. Some three hundred delegates and guests attended these highly successful gatherings. After preliminary general sessions of the Unions, the various sections and committees had separate meetings, and at the conclusion general sessions again were held on May 10 for the transaction of matters pertaining to the entire unions.

While there were some decided advantages of having the two unions meet at the same time and in the same place, many of the representatives, because of the necessary overlapping of sessions, could generally attend only the section or committee in which they were specifically interested. The only time when general intercourse became usually possible was at the social events, provision for which had been abundantly made by the National Committee of Italy. It was considered, however, that the experiment might be tried of having in future separate meetings of the two unions. Accordingly, the next meeting of the International Astronomical Union will be held at Cambridge, England, in 1925, and that of the International Geodetic and Geophysical Union at Madrid, Spain, in 1924—probably during September.

The following general report pertains specifically to the meeting

[1] The full report will appear in a volume to be published by the International Section of Terrestrial Magnetism and Electricity, containing the Proceedings and Reports submitted.

of the Section of Terrestrial Magnetism and Electricity of the International Geodetic and Geophysical Union. This section held seven well-attended sessions, May 4-9, twelve different countries being represented by thirty-three delegates and guests, viz.:

Australia (J. M. Baldwin, G. F. Dodwell, E. F. Pigot); *Belgium* (J. Jaumotte); *Brazil* (H. Morize); *France* (J. Bosler, H. Deslandres, E. Delcambre, E. Mathias, Ch. Maurain); *Great Britain* (C. Chree, A. L. Cortie, W. C. Parkinson, Arthur Schuster, Napier Shaw, G. C. Simpson); *Italy* (A. Alessio, F. Eredia, L. Palazzo, D. Pacini, G. Platania, A. Pochettino, G. B. Rizzo, C. Somigliana); *Japan* (K. Nakamura); *Poland* (J. Krassowski); *Spain* (J. Galbis, L. Rodés); *Sweden* (D. Stenquist, A. Wallén); *United States* (L. A. Bauer, G. W. Littlehales); *Canada* (E. Deville).

Organization.—Professor Tanakadate, who was unable to be present at Rome, had requested to be relieved of the presidency of the section, because of his inability to attend to the duties. The resignation was regretfully accepted and Dr. Charles Chree, who as vice-president had presided at all sessions, was elected at the closing session on May 9 president, and Professor Luigi Palazzo, vice-president; both of these officers, according to the statutes, serve for two terms. The secretary and director of the Central Bureau, Dr. Louis A. Bauer, continues in office until the next meeting, which will be at Madrid, Spain, about September, 1924. Directors J. Jaumotte (Belgium) and Ch. Maurain (France), and Professor A. Tanakadate (Japan), in addition to the three officers of the Section, were constituted the Executive Committee. It was agreed that administrative matters should be left to the Bureau, consisting of the officers of the Section.

Agenda.—Since the meeting at Brussels in July, 1919, when the International Section of Terrestrial Magnetism and Electricity was established, nearly three years have elapsed. While the organization of the work of the Section, because of the post-war conditions, could not proceed as rapidly as it was hoped, nevertheless, definite progress has been made regarding which the Agenda (Ordre du Jour) for the present meeting are at least one indication.[1] Perhaps for the first time we have had presented in so concrete a form the salient questions, both of a practical and theoretical nature, pertaining to the magnetic and electric states of our Earth and its atmosphere. It was not to be expected, nor, indeed, desirable, that

[1] See *Terr. Mag.*, vol. 26, pp. 151-152, 1921, for English text; the French text will be found in this publication, pages 99-100.

definite decisions on all the questions should be reached at the present meeting. However, it must be a source of gratification that by the united action of the National Committees the crucial questions and problems have received a definite formulation.

Reports.—Reports were presented showing the status of magnetic and electric work in the various countries represented, and containing the opinions of National Committees, leading organizations, and investigators on items of the Agenda. There were, furthermore, reports from committees constituted at the Brussels meeting, as also reports and letters expressing the views of some whose countries, either were not officially represented at Rome (Greece, New Zealand), or did not yet belong to the International Geodetic and Geophysical Union. Among the latter there were letters from E. van Everdingen (Holland); V. Carlheim-Gyllensköld (Sweden); C. Ryder (Denmark); and Adolf Schmidt (Germany).

Resolutions.—On the basis of all information on hand and the ensuing discussions on items of the Agenda, the appended twenty resolutions were passed. It will be noticed that the Executive Committee is empowered to formulate more definite recommendations on some of the mooted questions of procedure, especially at magnetic observatories, as soon as further information has been received by the secretary from all services and observatories engaged in magnetic or electric work, in response to a questionnaire to be sent out.

Committees.—Five committees were appointed: 1. Committee on Magnetic Surveys and International Comparisons of Instruments; 2. Committee on Observational Work in Atmospheric Electricity to Report on Objects, Instruments, and Methods; 3. Committee on Measures of Magnetic Characterization of Days; 4. Committee on Best Methods, Instruments, and Compilations for Polar Light Observations; and 5. Committee to Consider and Report on Best Methods and Instruments for Earth-Current Observations. The provisional organization of these committees is shown by the appended list. The Executive Committee, according to Resolutions 11 and 15, was empowered to add to the membership of committees, as additional countries join the Union, and to form any additional committees deemed necessary to put into effect the resolutions. Provision has also been made for consideration of questions concerning the relationship between solar and the earth's magnetic and electric phenomena in the following manner: 1. A

committee on solar radiation, under the chairmanship of Dr. George E. Hale, of which Dr. Bauer is a member, was formed by the International Astronomical Union; 2. The International Research Council at its Brussels meeting in July, 1922, has decided to assist in initiating studies of the correlations between solar and terrestrial phenomena, as this subject is one of the kind in which several unions are jointly interested.

Funds.—The balance, 30,892 francs, of the accumulated funds in hand, arising from the contributions, 1919-1922, of the adhering countries at the rate of four hundred francs per contributing unit, was made available to the Section. This is in addition to the sum of about fifteen hundred francs which had been supplied in 1921, for incidental expenses of the Section. There will, furthermore, be available during the period 1922-1924, from the contributions of adhering countries, annually an amount at the rate of 320 francs per contributing amount. It is estimated that the annual amount from this source will be about 22,000 francs. Hence the Section will have available for its various purposes during the period 1922-1924, in all about 75,000 francs,[1] which is subject to increase as additional countries join the Union. With the aid of the funds thus available it is hoped that matters of international concern and benefit may be energetically pursued, for example, frequent intercomparisons of magnetic standards, the chief expense of which during the past sixteen years has been borne by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington.

The secretary and Prof. E. Mathias, as alternate or substitute when necessary, were made members of the Finance Committee of the International Geodetic and Geophysical Union.

Publications.—Resolution 12 empowered the Executive Committee to incur the necessary expense for the publication in the most suitable form of the minutes and proceedings of the Rome meeting and of the various reports received, as well as for the issue of any additional publications which may be found desirable and which the available funds may permit. It is estimated that the volume of proceedings and reports will approximate three hundred octavo pages, and that it may be distributed early in 1923. By means of bulletins, issued from time to time, prompt information it is hoped may be given regarding matters of international interest,

[1] Approximately, according to present rate of exchange, about 5,900 United States dollars or 1,315 pounds sterling.

progress on mooted questions, actions taken and recommendations by the Executive Committee, committees of the Section and National Committees, latest values of the magnetic and electric elements at observatories, etc.

Officers of the International Geodetic and Geophysical Union and of its Section.—For convenience of reference there are given in the table below, besides the officers of the particular section of interest in this report, the officers of the entire Union and of the other sections. An additional section (Scientific Hydrology) was established at Rome.

OFFICERS OF INTERNATIONAL GEODETIC AND GEOPHYSICAL UNION, 1922—.

Officers of the Union

President: C. Lallemand.**
Vice-President: Presidents of the Sections.
Secretary-General: H. G. Lyons.**

Officers of the Sections

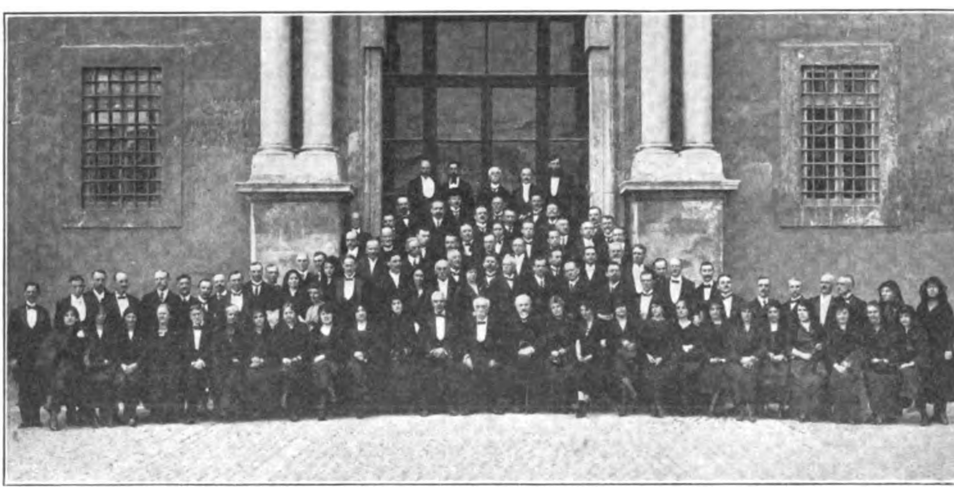
Section	President	Vice-President	Secretary
Geodesy	W. Bowie*	R. Gautier**	G. Perrier*
Seismology	H. H. Turner**	E. Oddone**	E. Rothé**
Meteorology	N. Shaw*	C. F. Marvin** E. Delcambre**	F. Eredia**
Terrestrial Magnetism and Electricity	C. Chree**	L. Palazzo**	Louis A. Bauer*
Physical Oceanography†	Prince of Monaco*	J. Parry*	G. Magrini*
Vulcanology	A. Lacroix**	H. S. Washington**	A. Malladra** G. Platania**
Scientific Hydrology	E. B. H. Wade**	A. Wallén**	G. Magrini**

Social Features.—Among the special social features may be mentioned: May 2, 3 p. m., Inaugural Ceremony at the Campidoglio, at which H. M., the King of Italy, was present; May 4, 9 p. m., Reception of the Delegates at the Campidoglio by the Municipality of Rome; May 8, 3 p. m., Visit to the Palatino at the Invitation of the Under Secretary of Antiquities and Fine Arts; and May 10,

* One additional term, beginning May, 1922, and continuing until next meeting (1924).
** Two additional terms, beginning May, 1922.
† The president has unfortunately died since the Rome meeting.

1 p. m., Visit to the Vatican and Audience with the Pope. Provision had also been made for several special excursions during and after the meetings, which gave further opportunity to the visiting delegates for social intercourse. At the closing session of the Union on May 10 several resolutions were passed in appreciation of the excellent arrangements made by Italy, both as regards the scientific sessions and the various social events.

Members of the Section of Terrestrial Magnetism and Electricity are also especially indebted to the genial director of the Italian Meteorological and Geodynamical Bureau, Professor Luigi Palazzo, for the part he took to ensure the success of the meeting.



ASTRONOMERS, GEOPHYSICISTS, AND GUESTS, ROME MEETING, MAY 1922.

Resolutions of International Section of Terrestrial Magnetism and Electricity.

(*Approved at the Rome Meeting, May 9, 1922*)

1. In view of the importance of securing world-wide cooperation in Terrestrial Magnetism and Electricity, and remembering the great contributions in these fields by scientists and instrument makers of countries not yet adherent to the Section, the hope is expressed that a day will come when the collaboration of all countries in the labors of the Section will become possible.

2. That the attention of directors of observatories be called to the importance of assuring themselves that the methods they employ for scale-value determinations of magnetographs are satisfactory, and that a general statement as to the methods be given in all observatory publications.

3. That in view of the diverse types of instruments in use, and diverse circumstances prevailing at the various stations, it is not advisable at present to recommend the adoption of any particular method of scale-value determination for magnetographs, nor any particular scale value, nor to specify an opinion as to the best elements to record.

4. That National Committees be requested to designate, if possible, one observatory in their respective countries for international intercomparisons of magnetic instruments, and to secure intercomparisons of magnetic instruments within their own countries at least once within the course of three years.

5. That the Committee on Magnetic Surveys and Intercomparisons of Magnetic Instruments formulate a definite scheme for securing intercomparisons of magnetic instruments between countries, and especially contiguous countries.

6. That the following are the localities at which additional magnetic observatories are most desirable: Northeast Canada, Northeast Siberia, Bermuda, St. Helena (or French West Africa), Italian North Africa, British South Africa, and Northeast Australia.

7. That the steps already taken by the New Zealand Government regarding the continuation of the Apia Observatory, Samoa, are highly commended, and it is hoped that the New Zealand Government may find it possible to provide for the continued full activities of the Observatory.

8. That the continuation by the Argentine Government of the Orcados Observatory is very much to be desired, in view of the high southerly latitude of the observatory and the opportunities thus afforded for obtaining highly important data.

9. That every magnetic observatory publish annually the monthly and annual mean values of the magnetic elements observed during the preceding year, for the purpose of the mutual exchange of such results.

10. That the organizations responsible for the various magnetic services be urged to make prompt publication of their data as completely as circumstances permit.

11. That the executive committee be empowered to constitute the committees recommended by the Section and to establish such additional committees as may be found necessary to put into effect the resolutions passed at the Rome meeting.

12. That the executive committee be authorized to incur the necessary expense for the publication in the most suitable form of the minutes and proceedings of the Rome meeting and of the various reports received, as well as for the issue of any additional publications which may be found desirable and which the available funds may permit.

13. That a committee be appointed to report on the best methods, instruments, and compilations for polar-light observations.

14. That in order to stimulate research regarding earth-currents, a committee be appointed to consider and report on the best methods and instruments.

15. That the executive committee be empowered to add to its membership or to the membership of the committees.

16. That it is desirable there should be in every country at least one observatory making systematic atmospheric-electric observations (especially of potential gradient, earth-air currents, conductivity, and number of ions) which are intercomparable amongst themselves and comparable with similar observations made in other countries.

17. That a committee be appointed on observational work in atmospheric electricity, to report on objects, instruments, and methods.

18. That in all publications concerning ionization, the author should indicate the value which he uses for the unit charge.

19. That, if funds allow, copies of disturbed magnetic curves continue to be published as at present, even when on a reduced scale, as they supply information at least potentially useful regarding the general features of disturbance. It is recognized, on the other hand, that for detailed examination photographic copies are much preferable, and that some scheme might usefully be arranged whereby anyone desiring such copies could secure them from certain observatories for a pre-arranged fee. As a preliminary to such a scheme directors of observatories are to be consulted.

20. That regarding items A6, 7, and 9 of the printed Agenda, namely, mean annual values and secular change, diurnal inequalities, and publications, the Executive Committee consider and formulate any recommendations they may think desirable.

(Signed) CHARLES CHREE, *President;* LOUIS A. BAUER, *Secretary.*

Committees of International Section of Terrestrial Magnetism and Electricity.

(*As Provisionally Constituted at Rome, May 9, 1922*).

1. *Committee on Magnetic Surveys and International Comparisons of Instruments:* Louis A. Bauer (chairman); U. de Azpiazu, J. M. Baldwin, A. Ferraz de Carvalho, C. Chree, M. Eginitis, N. H. Heck, A. Hermant, S. Kalinowski, O. Klotz, E. Mathias, H. Morize, L. Palazzo, N. Watanabe.

2. *Committee on Observational Work in Atmospheric Electricity to Report on Objects, Instruments, and Methods:* G. C. Simpson (chairman); J. Jaumotte, P. Langevin, D. Pacini, W. F. G. Swann.

3. *Committee on Measures of Magnetic Characterization of Days:* ——— ————— (chairman); R. L. Faris, A. Crichton Mitchell, R. Dongier, A. Tanakadate.

4. *Committee on Best Methods, Instruments, and Compilations for Polar Light Observations:* ——— ————— (chairman); H. Arctowski, Ch. Fabry, J. A. Fleming, Lord Rayleigh, R. F. Stupart.

5. *Committee to Consider and Report on Best Methods and Instruments for Earth-Current Observations:* A. Schuster (chairman); S. J. Mauchly (secretary), Ch. Maurain, L. Rodés, H. Nagoaka.

(Signed) Charles Chree, *President;* Louis A. Bauer, *Secretary.*

Union Géodésique et Géophysique Internationale.

conférence de rome, mai, 1922.

Ordre Du Jour.

DE LA SECTION DE MAGNÉTISME ET D'ÉLECTRICITÉ TERRESTRES.

1.—Ouverture de la Séance.
2.—Rapport du Secrétaire, Directeur du Bureau Central.
3.—Rapports variés (des Comités nationaux et spéciaux et sur les investigations).
4.—Questions diverses soumises à l'étude et à la considération des Comités spéciaux.
5.—But, champ d'activité et nom définitif à adopter pour la Section.
6.—Statuts et organisation future de la Section.
7.—Nomination et organisation des Comités.
8.—Résolutions soumises au vote.

Les questions soumises (No. 4) à l'étude et à la considération des Comités sont les suivantes:

A.—Magnétisme Terrestre.

1.—Instruments absolus.
- *a.* Méthodes électriques.
- *b.* Détermination des "constantes."
- *c.* Comparisons.

2.—Observations absolues.
- *a.* Méthodes.
- *b.* Procédés de réduction.

3.—Magnétographes.
- *a.* Détermination de la valeur des divisions de l'échelle.
- *b.* Valeurs des divisions de l'échelle à recommander.
- *c.* Éléments à enregistrer de préférence.

4.—Caractérisation des jours et l'activité magnétique.

5.—Relevé des courbes.
- *a.* Heure locale ou heure de Greenwich?
- *b.* Valeurs instantanées ou moyennes horaires?
- *c.* Si moyennes horaires, les 60 minutes sont-elles centrées à l'heure ou à la demi-heure?

6.—Moyennes annuelles et variation séculaire.
- *a.* Si d'après les courbes, avec quel mode de coupure des jours?
- *b.* Si d'après les observations absolues, avec quelles corrections?

7.—Inégalités diurnes.
- *a.* Déduites de l'ensemble ou de certains jours choisis, et comment?
- *b.* Corrections non périodiques.
- *c.* Coefficients de Fourier.

8.—Copies des courbes. Moyens de les obtenir et de les échanger.

9.—Publications
- *a.* Ce qu'il y a lieu de publier. Minimum désirable.
- *b.* Forme. *c.* Terminologie.

10.—Réseaux magnétiques.
- *a.* Densité des stations.
- *b.* Question d'une période internationale et de sa date.
- *c.* Procédés d'observation—leur exactitude.
- *d.* Reduction à une même époque.
- *e.* La construction des courbes isomagnétiques.
- *f.* Zones perturbées. Les anomalies et la géologie.
- *g.* Champ magnétique terrestre.
- *h.* Présentation des résultats.

11.—Variation des éléments magnétiques avec l'altitude.

12.—Ligne magnétique integrale et courants électriques aéroterrestres, leur détermination et leur compatibilité.

B.—Électricité Terrestre.

1.—Comment obtenir et publier de données complètes sur le gradient du potentiel, les courants aéroterrestres, la conductibilité et le nombre d'ions atmosphériques en la forme la plus uniforme et de la maniére la plus satisfaisante (formation d'un comité d'enquête sur les instruments et les méthodes).

2.—Observation des phénomènes électriques dans les couches supérieures de l'atmosphère.

3.—Aurores boréales (méthodes, instruments, compilations).

4.—Courants telluriques (méthodes, instruments, observations, publications).

5.—Rapports entre l'activité solaire et les phénomènes magnétiques et électriques observés à la surface de la terre.

Voeux de la Section Internationale de Magnétisme et d'Electricité Terrestres.

(*Adoptés à la Conférence de Rome, le 9 mai 1922.*)

1. Etant donnée l'importance qu'il y a à assurer une large coopération dans le monde en ce qui concerne le magnétisme et l'électricité terrestres, et en considération de la contribution considérable dans ces domaines apportée par les savants et les constructeurs de pays qui n' adhèrent pas encore à la Section, l'espoir est exprimé qu'un jour viendra où la collaboration de tous les pays aux travaux de la Section deviendra possible.

2. Que l'attention des directeurs d' observatoires soit appelée sur l'importance qu'il y a à vérifier eux-mêmes que les méthodes employées pour déterminer la valeur des divisions de l'échelle du magnétographe sont satisfaisantes, et qu'un exposé des méthodes établies soit donné dans les publications des observatoires.

3. Que, d'après la diversité des instruments en usage et des conditions correspondant aux diverses stations, il n'est pas désirable pour le moment, de recommander l'adoption d'une méthode particulière pour la détermination de la valeur des divisions de l'échelle du magnétographe, ni une valeur particulière; ni d' exprimer une opinion sur les éléments à enregistrer de préférence.

4. Que les Comités Nationaux soient priés de désigner, s'il est possible, un observatoire central pour leurs pays respectifs, chargé des comparaisons internationales des instruments magnétiques, et d'assurer dans leurs propres pays une comparaison des instruments.

5. Que le Comité chargé des levés magnétiques et des comparaisons internationales des instruments magnétiques, formule des règles définies pour assurer les comparaisons des instruments magnétiques, spécialement en ce qui concerne les pays contigus.

6. Qu'il soit établi des observatoires magnétiques additionnels dans les contrées suivantes, pour lesquelles cela est le plus désirable: Nord-Est du Canada, Nord-Est de la Sibérie, Les Bermudes, Sainte-Hélène (ou Afrique Occidentale Française), Nord Africain Italien, Afrique Anglaise du Sud, et Nord-Est de l'Australie.

7. Les dispositions déjà prises par le Gouvernement de la Nouvelle-Zélande pour le maintien de l'Observatoire d'Apia, Samoa, sont hautement approuvées et l'espoir est exprimé que le Gouvernement de la Nouvelle-Zélande aura la possibilité de permettre à cet observatoire la continuation de sa pleine activité.

8. Le maintien par le Gouvernement Argentin du service de l'Observatoire des Orcades est hautement désirable, à cause de la haute latitude sud de l'Observatoire et de la possibilité d'obtenir ainsi d'importantes données.

9. Que chaque observatoire magnétique publie annuellement les valeurs moyennes, mensuelles et annuelles, des éléments magnétiques relatives à l'année précédente, afin d'assurer l'échange mutuel de ces résultats.

10. Que les organisations responsables des différents services magnétiques soient promptes à assurer leurs publications d'une manière aussi complète que possible.

11. Que le Comité Exécutif ait le pouvoir d'instituer des comités recommandés par la Section, et d'établir de tels comités additionnels autant qu'il sera jugé nécessaire pour mettre à exécution les résolutions de la réunion de Rome.

12. Que le Comité Exécutif soit autorisé à faire la dépense nécessaire pour une publication, sous la forme la plus convenable des minutes et des procès-verbaux de la réunion de Rome, ainsi que des différents rapports reçus, et soit autorisé à faire toutes autres publications utiles, dans la limite des fonds disponibles.

13. Qu'un Comité soit chargé de faire un rapport sur les meilleures méthodes les meilleurs instruments et les publications relatives aux aurores polaires.

14. Qu'afin de stimuler les recherches concernant les courants telluriques, un Comité soit formé pour établir un rapport sur les meilleures méthodes et les meilleurs appareils.

15. Que le Comité Exécutif ait le pouvoir d'adjoindre à ses membres ou à ceux des autres comités des personnes qualifiées.

16. Qu'il y ait dans chaque pays au moins un observatoire faisant des observations systématiques d'électricité atmosphérique, spécialement de: gradient du potentiel, courant air-terre, conductibilité électrique, et nombre d'ions, de telle façon que ces observations soient comparables entre elles et comparables aux observations semblables faites dans les autres pays.

17. Qu'un Comité soit formé pour faire un rapport sur les sujets d'études, les instruments, et les méthodes relatives à l' électricité atmosphérique.

18. Que dans toutes les publications concernant l'ionisation, l'auteur indique la valeur qu'il admet pour l'unité de chargé.

19. Que, si les fonds le permettent, on continue à publier, comme on le fait actuellement, les reproductions des courbes perturbées, même à échelle réduite, vu qu'elles fournissent des renseignements qui pourront être utiles, sur le caractère général des perturbations. D'autre part, il est reconnu que, pour une étude détaillée, les copies photographiques sont à préférer, et qu'il serait utile d'établir un procédé permettant à ceux qui désirent de telles copies d'en obtenir de certains observatoires à un prix fixé d'avance. Avant de mettre à effet ce projet, on devrait consulter les directeurs des observatoires.

20. Que, en ce qui concerne les articles A6, 7 et 9, de l'Ordre du Jour imprimé, à savoir, moyennes annuelles, variation séculaire, inégalités diurnes et publications, le Comité Exécutif établisse et formule les recommandations qu'il jugera désirables.

(Signé) *Le Président*, CHARLES CHREE; *Le Secrétaire*, LOUIS A. BAUER.

SOME EXPERIMENTS ON THE PENETRATING γ RADIATION PRESENT IN THE ATMOSPHERE.

BY E. MARSDEN.

The present note deals with an experiment on the magnitude of the ionization due to penetrating radiation in a closed can on Mount Ruapehu (latitude 39°.25 S.; longitude 175°.6 E.; height, 9,200 feet = 2,800 meters).

According to Kolhörster,[1] the ionization in a closed ionization vessel, in free air, at an altitude of 2,800 meters is 4 ions per c.c. greater than that at sea level. Kolhörster's experiments were made with air in a zinc (?) ionization-vessel.

It is well known that the ionization due to γ rays in a vessel containing a gas with molecules of high atomic weight is greater than that in air. In the experiments to be described sulphur dioxide was used, and although this gas does not multiply the γ-ray effect so much as gases such as methyl iodide, yet, on account of its chemical stability when dry, and its relatively high condensation point, it is particularly suitable for the experiment in view. By using SO_2 in a closed vessel, the ionization due to γ rays is approximately doubled, while the ionization due to radioactive impurities in the material of the vessel (chiefly α-ray effect) is practically unaltered. Thus, any variations of penetrating γ radiation will relatively, to the whole leak, be greater than in the case of experiments made with air.

Further, it is well known that the ionization due to γ rays is, in the main, a secondary effect of β particles ejected from the walls of the measuring vessel, very little of the effect being due to secondary β particles from the gas itself. The secondary β particles have a range at normal temperature and pressure considerably greater than the average dimensions of an ionization-vessel.

The number of secondary β particles from various materials, and consequently the ionization due to γ rays in a closed vessel, increases with the atomic weight of the material: for instance, the ionization in a lead vessel is approximately twice that in one of

[1] Phys. Zeitschr. *XIV*, p. 1153, 1913.

brass. The main objection to increasing the γ-ray effect in this way is the difficulty of obtaining materials of high atomic weight without a large increase in radioactive impurity: for example, lead is notoriously radioactive on account of the presence of its isotope RaD, with the consequent production of polonium. By using old lead, however, the greater part of the RaD will have decayed, with consequent diminution of natural activity.

In some preliminary tests, a cylindrical brass can was used. The natural leak was obtained with air in the can by means of a Wilson tilted electroscope. The leak, due to γ rays from radium at a standard distance (1.5 meters) was also obtained. The can was then lined with various materials by preparing a solder by admixture of tin, and "wiping" or "tinning" the inside of the can, the average thickness of the coating being about 0.2 mm.

The results were as follows:

Inside coating of ionization can	Natural leak, Volts/minute	Effect of γ rays from standard Ra., corrected for natural leak
Brass	0.05	1.0
50 per cent old lead, 25 per cent Sn., 25 per cent Bi.	0.10	1.8
Pb. (old) + 5% Sn.	0.07	1.9
Sn.	0.115	1.5
Bi + 5% Sn.	0.145	1.95
Pb. (new) + 5% Sn.	0.115	1.85
Pb. (old) with sulphur dioxide	0.075 (approx.)	3.7

The new lead was ordinary, newly purchased, plumber's lead. The old lead had been used for roofing a house in Nelson, N. Z., about seventy years ago, and was as old as any readily available in New Zealand. The test shows that bismuth and new lead are unsuitable owing to radioactive impurity: so also was the tin used. The old lead increased the γ-ray effect by ninety per cent, and the natural leak by only forty per cent. This latter leak is increased partly by increase of the penetrating radiation effect, and possibly partly by the greater natural leak of the lead used than that of brass. The surface of the brass was thoroughly cleaned before use.

The test shows that for measuring increases of penetrating radiation of the γ-ray type, a vessel lined with old lead and filled with sulphur dioxide possesses considerable advantages compared with a brass vessel filled with air.

For the mountain experiment, two sets of apparatus were constructed, each consisting of a Wilson tilted electroscope and an ionization-can. The outside of the can was charged to + 200 volts, and the leak to a central rod was measured, using a guard ring to avoid conduction over the insulation, which was of the best ebonite.

Both ionization-vessels were made air-tight and fitted with arrangements for testing pressure. One vessel was of brass throughout and had a volume of 7,000 cubic centimeters, while the other of volume 9,000 cubic centimeters was lined with a thin coating of old lead, mixed with as small proportion of tin as would make it adhere successfully to the brass. Both were filled with SO_2 from a siphon where the SO_2 had remained for some considerable time previously, so that there was no radium emanation impurity.

The tilted electroscopes were constructed of thick copper to avoid local differences of temperature, and arrangements were made so that they could be used, if necessary, in a high wind. The author was agreeably surprised to find how robust these instruments are: the electroscopes and attached gold leaves successfully withstood the various journeys, and were carried in a vest pocket.

Camp was made at a height of 4,000 feet on the slopes of Ruapehu, which is a volcanic cone with the same kind of lava rocks from 4,000 feet upwards. At 4,000 feet, according to Kolhörster, there is practically no increase of ionization from sea level. Unfortunately, there was only one clear day on which measurements could be made at the top of the mountain, but on that day a stay of four hours at a height of 9,200 feet was obtained and measurements were made with both electroscopes. Comparative measurements at 4,000 feet were made before and after the ascent. The measurements were converted to ions per c.c. from a knowledge of the combined capacities of the ionization-chambers and electroscopes, which were determined experimentally.

The results obtained on January 24, 1922, were as follows:

Station	Ions per cubic centimeter	
	Brass can, 7,000 c.c. Capacity = 13.1 cm.	Lead lined can, 9,000 c.c. Capacity = 14.8 cm.
Before ascent, 4,000 ft.......	11	18
Mountain top, 9,200 ft......	11.5	19
After ascent, 4,000 ft.......	11.5	18

The measurements at 9,200 feet were only of a little better than eight per cent accuracy, while those at 4,000 feet were somewhat more accurate. The results show that the ionizations at 4,000 feet and 9,200 feet are the same to within one ion per c.c., even when the ionization-vessel is lead-lined and contains sulphur dioxide. Under such conditions, if we accept Kolhörster's result as due to γ rays, there ought to be about 4x3.7, i. e., 15 ions per c.c. difference between the two stations. The author hopes to repeat the experiments and to obtain a greater degree of accuracy.

It may be of interest to note that using similar apparatus to the above in January-February, 1921, at the Apia Observatory, Samoa, variations in ionization were observed at sea level as much as 30 per cent above and below the average. These variations were irregular from day to day and no simple correlation with meteorological conditions was obtained. The matter is being investigated further, both in Apia and Wellington.

In conclusion the author wishes to thank Mr. W. C. Harwood, B. Sc., for his kind and efficient assistance in these experiments.

Victoria University College, Wellington, N. Z.,
July 9, 1922.

UEBER DIE SELBSTAUFLADUNG KORPUSKULAR STRAHLENDER KOERPER.

VON E. SCHWEIDLER.

[*Summary.*—1. Tbe observed phenomena, which have led to hypotheses regarding the existence of corpuscular cosmic rays, are briefly discussed and the importance is pointed out of deducing the theoretical consequences resulting from the charged state of the emitting cosmic bodies. 2. The characteristics of corpuscular rays are discussed, especially the "radiation potential," P (quotient of the kinetic energy and the electric charge of a particle), and the magnetic deflectibility. 3. The stationary charge of a sphere, which spontaneously emits corpuscular rays into a surrounding vacuum, is computed; it is larger than the product Pa ("radiation potential" times radius of sphere), and increases with intensity of emission; the emitted particles are compelled to turn back at a distance A, the values of which are computed; numerical examples for the Moon, as the supposed source of radiation, are added. 4. The stationary charge during simultaneous spontaneous emission of positive and negative corpuscular rays is computed. 5. Analogous calculations are made on the assumption that a sphere with a strongly ionized surface emits a spontaneous radiation and hence on account of its charging, a compensating field-driven ion-radiation is emitted; in an equilibrium condition, therefore, at a great distance, there exist both positive and negative rays of equal average intensity and equal velocity; the results are applied to the case of the Sun and several numerical examples are given.]

1. EINLEITUNG.

Strahlungen korpuskularer Natur spielen in der kosmischen Physik eine wichtige Rolle. Zunächst sind es die Nordlichterscheinungen, die nach der von Birkeland aufgestellten und insbesondere von Störmer, Lenard und Vegard weiter entwickelten Theorie auf solche Strahlen zurückgeführt werden; ihre quantitativen Merkmale (Ladung, Masse, Geschwindigkeit) sind allerdings bisher nicht mit voller Sicherkeit anzugeben. Während aus der Lage des Gürtels grösster Nordlichthäufigkeit auf Strahlen sehr grosser magnetischer Steifigkeit (also entweder sehr schnelle β-Strahlen oder Strahlen grosser Masse) zu schliessen wäre, deuten die beobachteten räumlichen Verhältnisse (Höhe und vertikale Ausdehnung der Lichterscheinungen) unter Berücksichtigung der Bahnform und der Absorption auf negative Strahlen verhältnismässig geringer Steifigkeit.[1] Diesen Widerspruch sucht bekanntlich Störmer durch die Annahme zu lösen, dass ausserterrestrische ringförmige Ströme—ebenfalls korpuskularer Natur—

[1] C. STÖRMER, *Geofys. Publ.* 1, Nr. 5, Kristiania, 1921.

schon weit ausserhalb der Atmosphäre die Bahnen der ankommenden Teilchen durch ihr magnetisches Feld beeinflussen. Auch die Wirkung der elektrostatischen Abstossungskräfte zwischen den Teilchen eines Schwarmes ist theoretisch noch nicht ganz befriedigend aufgeklärt.

Neben den Nordlichten sind aber noch andere Erscheinungen bekannt, die auf die Existenz kosmischer Korpuskularstrahlen hinweisen. Zunächst ist es die von Gockel und von Hess zuerst beobachtete, in höheren Schichten der Atmosphäre ionisierend wirksame sehr durchdringende Strahlung, die wenigstens indirekt (als von ihnen erzeugte Sekundärstrahlung) auf von aussen kommende Korpuskularstrahlen zurückgeführt werden könnte. Ferner ist aus der Aufrechterhaltung der negativen Erdladung auf eine von aussen kommende, sehr durchdringende negative Korpuskularstrahlung geschlossen worden (Simpson,[2] Swann,[3] Schweidler,[4] Seeliger.[5])

Endlich hat Bauer[6] aus erdmagnetischen Daten die Existenz eines Stromsystems festgestellt, dessen Stromlinien im allgemeinen in den Polarkappen der Erde aus ihrer Oberfläche austreten und im Aequatorialgürtel eintreten. Auch er hält eine Erklärung durch Korpuskularstrahlen für möglich, die dann in niedrigen und mittleren Breiten positive, in hohen Breiten negative Ladungen durch die Erdatmosphäre hindurch transportieren; eventuell wären auch Strahlen entgegengesetzter Ladung und Richtung (also von der Erde ausgehend) denkbar. In jedem Falle wäre ihnen eine ausserordentlich grosse Durchdringungsfähigkeit zuzuschreiben.

Bei allen diesen auf mehr oder minder ausreichenden Beobachtungstatsachen beruhenden und daher in verschiedenem Grade präzisierten Hypothesen erscheint es nun von Interesse, die Konsequenzen zu betrachten, zu denen man in Bezug auf den Ladungszustand der die Strahlen aussendenden Weltkörper gelangt.

2. DIE CHARAKTERISTISCHEN KONSTANTEN KORPUSKULARER STRAHLEN.

Eine sogenannte "homogene" Korpuskularstrahlung ist eindeutig bestimmt durch die Zahl, Masse, Ladung, und Geschwindigkeit der Teilchen. Wir bezeichnen die in der Zeiteinheit (sec) die

[2] G. C. SIMPSON, *Nature*, **69**, 270, 1904.
[3] W. F. G. SWANN, *Terr. Mag.* **20**, 105, 1915.
[4] E. v. SCHWEIDLER, *Wien Ber.* **127**, 515, 1918, und *Ann. d. Phys.* (4) **63**, 726, 1920.
[5] R. SEELIGER, *Ann. d. Phys.* (4) **62**, 446, 1920.
[6] L. A. BAUER, *Terr. Mag.* **25**, 145, 1920.

Flächeneinheit (cm^2) des Querschnittes eines Bündels passierende Teilchenzahl mit z; die Ladung (in statischen Einheiten) mit e; die Masse (in g) oder genauer—in Berücksichtigung der Abhängigkeit der Masse von der Geschwindigkeit—die Ruhmasse mit m; endlich die Geschwindigkeit mit $v = \beta.c$, wobei c die Lichtgeschwindigkeit und β ein zwischen 0 und 1 liegender dimensionsloser Faktor ist.

Für die bei der Lorentz-Transformation auftretende Grösse $\frac{1}{\sqrt{1-\beta^2}}$, führen wir die abkürzende Bezeichnung η ein; die kinetische Energie eines Teilchens ist dann nach den Formeln der speziellen Relativitätstheorie:

$$E = mc^2 \left(\frac{1}{\sqrt{1-\beta^2}} - 1 \right) = mc^2 (\eta - 1)$$

was bekanntlich bei kleinen Geschwindigkeiten ($\beta << 1$) in die gewöhnliche Formel $E = \frac{1}{2} mc^2 \beta^2$ übergeht.

Drücken wir E als Produkt Pe einer Spannung P und der Teilchenladung e aus, so bedeutet P diejenige Potentialdifferenz (in *stat.* Einh.), die das ursprünglich ruhende Teilchen in einem beschleunigenden Felde durchlaufen muss, um die Endgeschwindigkeit βc zu erhalten, bezw. die Potentialdifferenz, die bei verzögerter Bewegung das Teilchen von der Anfangsgeschwindigkeit βc, auf die Geschwindigkeit Null abbremst. Wir wollen P, das (in Volt gemessen) gewöhnlich die "Voltgeschwindigkeit" genannt wird, hier kurz das "*Strahlpotential*" nennen und durch $P = \frac{mc^2}{e} (\eta - 1)$ darstellen. Durchläuft ein Teilchen mit dem Strahlpotential P_0 eine beschleunigende oder bremsende Potentialdifferenz Π, so ist am Ende der Bahn sein Strahlpotential $P = P_0 \pm \Pi$. Für die Berechnung der Zeit, die es zu dieser Strecke braucht, ist es von Bedeutung, dass trotz Aenderung der kinetischen Energie die Geschwindigkeit sich nur wenig ändert, falls β_0 sehr gross ist. Durchläuft z. B. ein Teilchen mit $\beta_0 < 0.3$ in einem bremsenden Feld konstanter Stärke bis zum Umkehrpunkt die Strecke l, so ist die Bewegung sehr annähernd eine gleichförmig verzögerte und daher die mittlere Geschwindigkeit $\bar{v} = \frac{1}{2} \beta_0 c$. Ist dagegen z. B. $\beta_0 =$ 0.9999 und l bei entsprechend verstärktem Felde ebenso gross wie früher, so ist nach Durchlaufen von 0.98 l die Geschwindigkeit immer noch grösser als 0.9 c, die Bremsung erfolgt rapid im letzten

kleinen Stück der Bahn und die mittlere Geschwindigkeit liegt nur wenige Prozente unter der Anfangsgeschwindigkeit.

Das für das Verhalten in magnetischen Feldern charakteristische Produkt $H\rho$ (in Γ. cm) aus magnetischer Feldstärke und Krümmungsradius ist in unserer Bezeichnungsweise:

$$H\rho = \frac{mc^2}{e} \cdot \eta\beta$$

denn $m\eta$ ist die "transversale Masse" und βc die Geschwindigkeit. Für sehr grosse Geschwindigkeiten (β nahe gleich 1, η gross gegen 1) werden daher die Grössen $H\rho$ und P (in stat. Einh.) einander nahezu gleich. Die numerischen Werte veranschaulicht die folgende Tabelle:

β	η	$(\eta-1)$	$\eta\beta$
0.0	1.000	0.000	0.000
0.1	1.005	0.005	0.100
0.2	1.020	0.020	0.204
0.3	1.048	0.048	0.314
0.4	1.091	0.091	0.436
0.5	1.155	0.155	0.578
0.6	1.250	0.250	0.750
0.7	1.400	0.400	0.980
0.8	1.667	0.667	1.334
0.9	2.294	1.294	2.065
0.95	3.203	2.203	3.043
0.99	7.089	6.089	7.018
0.995	10.01	9.012	9.962
0.999	22.36	21.36	22.34
$1-10^{-4}$	70.71	69.71	70.70
$1-10^{-5}$	223.6	222.6	223.6
$1-10^{-6}$	707.1	706.1	707.1

Für die Berechnung von $P = \frac{mc^2}{e}(\eta - 1)$

$$\text{und } H\rho = \frac{mc^2}{e}\eta\beta$$

gelten die Werte:

$$\frac{mc^2}{e} = 1694 \text{ bei Elektronen}$$

$$= 3.13 \times 10^6 \text{ bei } H\text{-Kernen}$$

$$= 6.21 \times 10^6 \text{ bei } \alpha\text{-Teilchen}$$

und leicht analog zu ermittelnde Werte für positive Atomionen anderer Art.

3. DIE SELBSTAUFLADUNG DURCH SPONTANE KORPUSKULARSTRAHLUNG.

Wir nehmen an, dass eine feste Kugel vom Radius a von absolutem Vakuum ungeben sei und spontan, d. h. ohne Mitwirkung eines elektrischen Feldes, nach Art eines radioaktiven Körpers eine homogene Korpuskularstrahlung (Strahlpotential P_0) aussende. Es sei z die Zahl der Teilchen pro Flächen- und Zeiteinheit, also $I = 4\pi a^2 ze$ der ganze ausgesandte Strom. Der Einfachheit halber setzen wir weiter voraus, dass die Strahlung die Oberfläche überall *senkrecht* verlasse.

Die Kugel nimmt dann eine Ladung entgegengesetzten Vorzeichens an, erzeugt dadurch ein bremsendes Feld und erreicht asymptotisch einen stationären Ladungszustand, bei dem in der Zeiteinheit ebensoviele Teilchen auf die Kugel zurückgetrieben als spontan emittiert werden. Es sei Emission negativer Teilchen und daher positive Aufladung vorausgesetzt; der umgekehrte Fall ist dann natürlich durch Vorzeichenswechsel in den Formeln erledigt. Zunächst—vom ungeladenen Zustand beginnend—gehen die emittierten Teilchen in unendliche Entfernung, solange bis die Kugel eine Ladung im Betrage $P_0 \, a$ angenommen hat; sobald dieser Grenzwert überschritten ist, werden alle weiterhin ermittierten Teilchen in endlicher Entfernung A zur Umkehr gebracht und gelangen nach einer gewissen Zeit $2\ T$ (Steigdauer und Falldauer) wieder zurück. Im stationären Zustande ist die Ladung der Kugel $Q_a > P_0 a$, die zwischen $r = a$ und $r = A$ auf dem Hin- oder Rückwege befindilchen Teilchen haben eine Gesamtladung $-Q'$ und es muss die Bedingung erfüllt sein:

$$Q_a - Q' = P_0 a \tag{1}$$

Andererseits muss gelten:

$$Q' = 4\pi a^2 ze \ . \ 2T = I.2T \tag{2}$$

da eben die negative "Teilchenatmosphäre" aus den innerhalb der Zeit $2T$ emittierten Teilchen besteht.

Die stationäre Ladung Q_a, die Umkehrentfernung A und die Steigdauer T sind also abhängig von P_0, a und I. Die Berechnung dieser Grössen und der Feldverteilung im allgemeinen Falle ist ziemlich kompliziert; es seien daher hier nur einige Spezialfälle bahandelt.

Es werde angenommen, dass die Anfangsgeschwindigkeit β_0, klein und daher die Teilchenmasse praktisch konstant sei; ferner dass die Emission I so klein sei, dass das Feld der Raumladung $-Q'$ vernachlässigt werden kann. Dann lässt sich zu jedem vorge-

gebenen Werte der Umkehrentfernung A die zugehörige Ladung Q_a und die Steigdauer T berechnen. Zunächst folgt aus den Potentialwerten $V_a = \frac{Q_a}{a}$ und $V_A = \frac{Q_a}{A} = V_a - P_0$ die Gleichung:

$$Q_a\left(\frac{1}{a} - \frac{1}{A}\right) = P_0 = \frac{m\beta_0^2 c^2}{2e} \qquad (3)$$

Ferner folgt aus der für den Fall eines Teilchens im Felde der Ladung Q_a geltenden Differentialgleichung: $m\frac{d^2r}{dt^2} = -e\frac{Q_a}{r^2}$ und aus der Anfangsbedingung, dass $r = A$ und $\frac{dr}{dt} = 0$ für $t = 0$, nach Integration die Gleichung:

$$\frac{r}{A}\sqrt{\frac{A}{r} - 1} + \arctan\sqrt{\frac{A}{r} - 1} = \sqrt{\frac{2Q_a e}{A^3 m}} \cdot t$$

und hieraus für die Falldauer T:

$$T = \sqrt{\frac{A^3 m}{2Q_a e}}\left[\frac{a}{A}\sqrt{\frac{A}{a} - 1} + \arctan\sqrt{\frac{A}{a} - 1}\right] \qquad (4a)$$

oder unter Berücksichtigung der Gleichung (3):

$$T = \frac{A}{\beta_0 c}\sqrt{\frac{A}{a} - 1}\left[\frac{a}{A}\sqrt{\frac{A}{a} - 1} + \arctan\sqrt{\frac{A}{a} - 1}\right] = \frac{A}{\beta_0 c} \cdot f\left(\frac{A}{a}\right) \qquad (4b)$$

Numerische Werte der hier auftretenden Funktion $f\left(\frac{A}{a}\right)$ gibt folgende Tabelle:

$\frac{A}{a}$	1	1.25	2	5	10	50	101	401	901	10001
$f\left(\frac{A}{a}\right)$	0	0.432	1.285	3.02	4.65	11.0	15.7	31.4	47.2	158

Vermöge der Gleichungen (1) und (2) ist nun $Q_a = 2\,T\,I + P_0 a$, andererseits nach Gleichung (3) $Q_a = P_0 a \frac{A}{A-a}$, also

$$2\,I\,T = P_0 a \frac{a}{A-a} \qquad (5)$$

Es kann somit aus (4*b*) und (5) zu einem vorgegebenen Werte A berechnet werden, welche Emission I dazu nötig ist; die Formel (5) gilt nur, wenn A gross gegen a, da nur dann die Voraussetzung erfüllt ist, dass $-Q'$ vernachlässigt werden kann.

Ein numerisches Beispiel sei das folgende: eine Kugel von der Grösse des Mondes ($a = 1.74 \times 10^8$ cm, $4\pi a^2 = 38 \times 10^{16}$ cm²) sende β-Strahlen mit der Anfangsgeschwindigkeit $\beta_0 = 0.3$, Strahlpo-

tential $P_0 = 82$ stat. Einh. aus. Wenn die Umkehrentfernung $A = 401a$ sein soll (also ungefähr doppelt so gross wie die Distanz Mond-Erde), so berechnet sich nach (4*b*) und obiger Tabelle die Steigdauer $T = \frac{6.98 \text{x} 10^{10}}{0.9 \text{ x} 10^{10}} \text{ x } 31.4 = 245$ sec und daraus weiter nach (5) $I = 0.72 \text{x} 10^5 \frac{\text{stat.-Einh.}}{\text{sec}} = 1.5 \text{x} 10^{14} \frac{\text{Elem. quanten}}{\text{sec}}$, bezw. die Zahl $z = 4 \text{x} 10^{-4} \frac{\beta\text{-Strahlen}}{\text{cm}^2.\text{ sec}}$. Für $A = 101a$, also rund die halbe Distanz Mond-Erde, wird analog $T = 30.5$ sec und $I = 0.49 \text{x} 10^{16}$ $\frac{\text{Elem. quanten}}{\text{sec}}$ oder $z = 130 \text{x} 10^{-4} \frac{\beta\text{-Strahlen}}{\text{cm}^2 \text{ sec}}$.

Je höher I, bezw. z wird, um so höher ist Q_a, um so kleiner A und T. Schon bei ganz schwacher β-Strahlung der Mondoberfläche ($0.01 \frac{\beta \text{ Str.}}{\text{cm}^2 \text{ sec}}$) würden die Teilchen die Erde nicht mehr erreichen, wobei der Mond als absolut atmosphärenlos angenommen ist. Zum Vergleich sei bemerkt, dass eine Oberfläche von der Beschaffenheit der Erdrinde etwa $7 \text{x} 10^{-3}$ β-Strahlen pro cm^2 und sec aussendet.

Bei schnellen Strahlen wird allerdings die einer vorgegebenen Entfernung A zugeordnete Steigdauer verkleinert, P_0 vergrössert, also I beträchtlich vergrössert. Es lässt sich aber leicht berechnen, dass selbst bei einer enorm raschen (experimentell nicht bekannten) β-Strahlung mit $\beta_0 = 0.999$, $P_0 = 35500$ stat. Einh. die zu $A = 101a$ gehörige Emission auf das rund 20000 fache des vorigen Beispieles erhöht würde und somit auch in diesem Falle eine β-Strahlung von $200 \frac{\text{Strahlen}}{\text{cm}^2 \text{ sec}}$, was bei radioaktiven Messungen als eine zwar gut messbare, aber immerhin schwache Strahlung bezeichnet würde, nicht mehr die Erde erreichen würde.

Für eine fiktive α-Strahlung mit $\beta_0 = 0.1$, $P_0 = 31000$ ergibt sich durch analoge Rechnung, dass zu $A = 101a$ eine Emission von $z = \frac{\alpha\text{-Strahlen}}{\text{cm}^2 \text{ sec}}$ zugeordnet ist.

Zusammenfassend kann man also sagen, dass bei Körpern von den Dimensionen der Weltkörper schon eine für unsere Beobachtungsmethoden schwache oder höchtens mässige Emission korpuskularer Strahlen durch Aufladung des emittierenden Körpers ein bremsendes elektrisches Feld erzeugt, das die Teilchen schon in relativ geringer Entfernung zur Umkehr zwingt und nicht bis zu benachbarten Weltkörpern kommen lässt. Der emittierende Körper nimmt dabei im stationären Zustande eine Ladung an, die grösser als $P_0 a$ ist. Mit wachsender Stärke der Emission steigt diese Ladung, während die Umkehrentfernung abnimmt.

4. DIE SELBSTAUFLADUNG BEI GLEICHZEITIGER SPONTANER EMISSION POSITIVER UND NEGATIVER STRAHLUNG.

Wie früher sei eine Kugel (Radius a) gegeben, die sich in einem Vakuum befindet und gleichzeitig eine positive Strahlung der Gesamtintensität I_1 und eine negative I_2 aussende, wobei $I_2 > I_1$, so dass die Kugel eine positive Ladung annimt. P_0 sei wieder das Strahlpotential der negativen Strahlung.

Unter der (physikalisch nicht realisierbaren) Voraussetzung, dass die negative Strahlung *absolut homogen* sei und die Oberfläche genau senkrecht verlasse, *existiert dann überhaupt kein stationärer Ladungszustand.* Denn ist $Q_a \leqq P_0 a$, so gehen alle Teilchen ins Unendliche und infolge des Ueberwiegens der negativer Emission wächst Q_a über den Betrag $P_0 a$ an. Ist aber $Q_a > P_0 a$, so gelangen schliesslich alle emittierten negativen Teilchen wieder zurück, während die fortgehende positive Strahlung I_1 eine Abnehme von Q_a unter $P_0 a$ bewirkt. Das Resultat wäre ein periodisches Schwanken um den Betrag $P_0 a$.

Nehmen wir aber an, dass die Anfangsgeschwindigkeiten, bezw. Strahlpotentiale der negativen Teilchen nicht absolut gleich, sondern über ein beliebig kleines Intervall P_0 bis $P_0 + \triangle P_0$ verteilt sind, so lässt sich stets ein dazwischen liegenden Wert $\overline{P}$ angegeben, derart dass die Emission aller Teilchen, deren $P > \overline{P}$ ist, den Betrag I_1 annimt und somit die positive Emission kompensiert. Pa ist dann die stationäre Ladung der Kugel.

5. DIE SELBSTAUFLADUNG EINES SPONTAN STRAHLENDEN IONISIERTEN KÖRPERS.

Im Gegensatze zu den Voraussetzungen der vorigen Abschnitte sei angenommen, dass der emittierende Körper in seiner Oberflächenschichte eine sehr grosse Zahl freier Elektrizitätsträger (Ionen) enthalte, z. B. ein glühender Gasball wie die Sonne oder ein fester Körper mit stark ionisierter Atmosphäre wie die Erde sei.

Wie nehmen ferner wieder eine spontane, negative, senkrecht austretende homogene Korpuskularstrahlung vom Strahlpotential P_0 und der Gesamtstärke I an. Das von der Selbstaufladung erzeugte Feld treibt die in der Oberfläche ruhenden positiven Ionen nach aussen und es tritt ein stationärer Zustand ein, sobald der Ionenstrom die spontane Emission kompensiert. Die Berechnung des dazu nötigen Feldes erfordert die Lösung eines Problems, das man als Ermittlung des "*Raumladungsgrenzstromes im Vakuum*

zwischen konzentrischen Kugelflächen" bezeichnen kann. Analoge Probleme, die sich aber auf den Grenzstrom zwischen parallelen ebenen Platten oder zwischen konzentrischen Zylinderflächen beziehen, wurden von Langmuir[7] und von Schottky[8] gelöst.

Es werde also zunächst die folgende Aufgabe behandelt: Gegeben ist eine Kugel mit stark ionisierter Oberfläche und dem Radius a innerhalb einer leitenden konzentrischen Hohlkugel mit dem Radius A; zwischen beiden sei Vakuum. Wenn die innere Kugel auf dem Potential Null, die äussere auf dem konstanten Potentiale $-V_A$ gehalten wird, geht ein strom positiver Ionen von innen nach aussen, dessen Stärke I zu berechnen ist.

Unter der Voraussetzung, dass die Endgeschwindigkeit der positiven Ionen (Masse m, Ladung e) nach Durchlaufen der Potentialdifferenz V_A immer noch klein gegen die Lichtgeschwindigkeit sei, gilt nach Langmuir (*l. c.*):

a. Zwischen *ebenen Platten* in der Distanz A ist bei der Spannung V_A die Stromdichte

$$i = \frac{1}{9\pi} \sqrt{\frac{2e}{m}} \cdot \frac{V_A^{\frac{3}{2}}}{A^2}$$

b. Zwischen *konzentrischen Zylindern* (Radien a und A) ist der Strom pro Längeneinheit:

$$j = \frac{2}{9} \sqrt{\frac{2e}{m}} \cdot \frac{V_A^{\frac{3}{2}}}{A\phi(\frac{A}{a})}$$

wobei ϕ eine durch eine unendliche Reihe darstellbare Funktion ist, die bei wachsendem Argument sich rasch dem Grenzwert 1 nähert.

c. Schliesslich beweist Langmuir, dass auch bei *beliebig gestalteten Elektroden* der Gesamtstrom I proportional zu $V_A^{\frac{3}{2}}$ ist.

Es bleibt also für den hier vorliegenden Fall noch die Abhängigkeit des I von a and A zu bestimmen.

In diesem Falle gilt für eine Entfernung r, in der das Potential den Wert $-V(r)$ hat

$$\frac{mv^2}{2} = e\ V\ (r) \tag{6}$$

Eine zweite Gleichung erhalten wir aus der Kontinuitätsbedingung, dass das Produkt aus der Ladung einer Kugelschale, die von r bis $r + dr$ reicht, und der dort vorhandenen Ionengeschwindigkeit v den konstanten Wert Idr haben muss. Da nun die Feld-

[7] I. Langmuir, *Phys. Rev.* (2) **2**, 450, 1913; *Phys. Zeitschr.* **15**, 348 u. 516, 1914.
[8] W. Schottky, *Phys. Zeitschr.* **15**, 526, 1914.

stärke, durch $\frac{dV}{dr}$, die gesamte innerhalb r befindliche Ladung durch $r^2 \frac{dV}{dr}$ und somit die Ladung der Kugelschale durch $d[r^2 \frac{dV}{dr}]$ gegeben ist, folgt:

$$v \frac{d}{dr} [r^2 \frac{dV}{dr}] = I \tag{7}$$

und unter Berücksichtigung der Gleichung (6) weiter

$$\sqrt{V} \; \frac{d}{dr} [r^2 \frac{dV}{dr}] = \sqrt{\frac{m}{2e}} \, . \, I = K \tag{8}$$

Durch die Substitution von neuen Variablen

$$\xi = \log \text{nat} \frac{r}{a} \text{ und } \psi = V^{3/4}$$

geht die Differentialgleichung (8) über in

$$12\psi \frac{d^2\psi}{d\xi^2} + 4 \left(\frac{d\psi}{d\xi}\right)^2 + 12\psi \frac{d\psi}{d\xi} = 9K \tag{9}$$

Die Darstellung von ψ durch eine Potenzreihe und zwar unter Berücksichtigung der Anfangsbedingung, dass für $r = a$ oder $\xi = 0$; $V = 0$ und daher $\psi = 0$ ist, in der Form $\psi = \alpha_1\xi + \alpha_2\xi^2 + \ldots\ldots$ $= \alpha_1 \xi \left[1 + \frac{\alpha_2}{\alpha_1} \xi + \frac{\alpha_3}{\alpha_4}\xi^2 + \ldots\ldots\right]$ liefert dann aus Gleichung (9) für die Werte der Koeffizienten:

$$\alpha_1 = \tfrac{3}{2} \sqrt{K}; \; \alpha_2 = - \tfrac{3}{10} \alpha_1; \; \alpha_3 = \tfrac{9}{50} \alpha_1; \; \alpha_4 = - \tfrac{36}{1000} \alpha_1; \ldots.$$

und somit die Gleichung

$$\psi = V^{3/4} = \tfrac{3}{2} \sqrt{K} \log \text{nat} \tfrac{r}{a} [1 - \tfrac{3}{10} \log + \tfrac{18}{100} \log^2 - \tfrac{36}{1000} \log^3 + \ldots.] \tag{10}$$

oder

$$V_A = \left(\frac{3}{2}\right)^{\frac{4}{3}} \left(\frac{m}{2e}\right)^{\frac{1}{3}} I^{\frac{2}{3}} \left(\log \text{nat} \frac{A}{a}\right)^{\frac{4}{3}} \left[1 - \frac{3}{10} \log + \ldots\ldots\right]^{\frac{4}{3}} \tag{10a}$$

beziehungsweise:

$$I = \tfrac{4}{9} \sqrt{\frac{2e}{m}} \; \frac{V_A^{\frac{3}{2}}}{\left(\log \text{nat} \frac{A}{a}\right)^2 \left[1 - \frac{3}{10} \log + \ldots\ldots\right]^2} \tag{10b}$$

Bei wachsender Entfernung der Elektroden steigt also die zur Erziehung eines gegebenen Stromes I notwendige Spannung V_A ebenso wie bei den von Langmuir behandelten Fällen ins Unendliche und zwar hier logarithmisch mit A. Von einer geladenen ionisierten Kugel wäre also bei endlicher Spannung überhaupt kein endlicher stationärer Strom in den umgebenden unendlichen Raum zu erzielen, im Gegensatz z. B. zu einer geladenen Kugel in

einem unendlich ausgedehnten nach dem Ohm'schen Gesetze leitenden Medium. Aber diese Unmöglichkeit beruht auf der Wirkung der Raumladung und fällt weg, wenn in hinreichender Entfernung die positive Raumladung der abströmenden Ionen durch eine negative Raumladung kompensiert wird.

Dies ist der Fall bei dem von uns ursprünglich betrachteten Vorgang, wo die ionisierte Kugel gleichzeitig eine negative Emission I besitzt. Im stationären Zustand tritt dann folgende Feldverteilung ein: die Kugel lädt sich auf ein positives Potential Π auf; für $r>a$ nimmt $V(r)$ zunächst langsam, dann rasch, dann nach Ueberschreitung eines Wendepunktes wieder langsamer auf den Wert Null in $r=\infty$ ab; die Raumdichte ist überall positiv und sinkt mit wachsenden r asymptotisch und zwar rascher als $\frac{1}{r^2}$ abnehmend auf Null. Die Bedingung hierfür ist, dass für grosse Werte von r die *Geschwindigkeiten* der spontan emittierten negativen Teilchen und der durch das Feld beschleunigten positiven Ionen *gleich* werden, da sowohl die Raumdichten als auch die Stromdichten (Produkte aus Raumdichte und Geschwindigkeit) gleich sein sollen.

Nun ist in grosser Entfernung für die spontane negative Strahlung mit dem ursprünglichen Strahlpotential P_0 infolge der Verzögerung $P_\infty = P_0 - \Pi$, während die feldgetriebenen positiven Ionen schliesslich ein Strahlpotential Π erhalten.

Beziehen wir daher den Index 1 auf die spontan emittierten Teilchen, den Index 2 auf die feldgetriebenen Ionen, so gilt nach den im Abschnitt (2) angeführten Beziehungen:

$P_0 - \Pi = \frac{m_1 c^2}{e_1}(\eta_1 - 1)$ und $\Pi = \frac{m_2 c^2}{e_2}(\eta_2 - 1)$ und somit, da für $r=\infty$: $\beta_1 = \beta_2$ und daher auch $\eta_1 = \eta_2$, die Gleichung

$$\frac{P_0 - \Pi}{\Pi} = \frac{m_1 e_2}{m_2 e_1} \text{ oder } \Pi = P_0 \frac{m_2\, e_1}{m_2\, e_1 + m_1\, e_2} \tag{11}$$

Diese Gleichung (11) muss auch dann erfüllt sein, wenn die anfänglich—zur Berechnung von (10)—vorausgesetzte Bedingung, dass die Endgeschwindigkeit $\beta_2 c$ für $r=\infty$ klein gegen die Lichtgeschwindigkeit sei, *nicht mehr* erfüllt ist. Nur die Feldverteilung in der Umgebung der emittierenden Kugel wird dann verändert, derart dass das Gebiet merklicher Raumdichte sich weiter hinaus erstreckt.

Einsetzen numerischer Werte zeigt, dass bei spontaner *Elektronenstrahlung* (β-Strahlung) und *H-Ionen* als Trägern der feldgetriebenen Strahlung $e_2 = e_1$, $m_2 = 1848\ m_1$, also $\Pi = \frac{1848}{1849} P_0$ wird. Umgekehrt wäre bei spontaner H-Strahlung und feldgetriebener Kathoden- (Elektronen-) Strahlung dann $\Pi = \frac{1}{1849} P_0$ und analog bei spontaner α-Strahlung $\Pi = \frac{1}{3669} P_0$.

Bei *Anwendung auf die Sonne* ergibt sich daraus das bemerkenswerte Resultat: ob man nun von der Birkeland-Störmer'schen Hypothese einer spontanen *Elektronen-emission* der Sonne ausgeht oder, der ursprünglichen Auffassung Vegard's folgend, eine spontane *positive Strahlung* annimmt, in jedem Falle müssen im stationären Zustand in grosser Entfernung beide Strahlengattungen vorhanden sein und zwar mit gleicher mittlerer Intensität und mit gleicher Teilchengeschwindigkeit, so dass entsprechend der grösseren Masse die positive Strahlung eine grössere magnetische Steifigkeit und Durchdringungsfähigkeit besitzt als die negative.

Bekanntlich wurde in mässigen Breiten (Deutschland, England) häufig—ohne jeden Zusammenhang mit ausgesprochenen Nordlichterscheinungen oder magnetischen Störungen—mittels hinreichend lichtstarker Spektroskope die Nordlichtlinie im Lichte des nächtlichen Himmels beobachtet (Wiechert, Rayleigh) und daraus manchmal auf ein allerdings schwaches aber permanentes Nordlicht viel grösserer räumlicher Verbreitung geschlossen. Bei der gewöhnlichen Auffassung ist es eigentlich nicht recht verständlich, warum die magnetisch steife, aber schwache Strahlung so häufig, dagegen die stark ablenkbare intensive Strahlung, welche die Nordlichter im gewöhnlichen Sinne des Wortes erzeugt, seltener ist. Diese Tatsache wird verständlich, wenn wir annehmen, dass fast immer von irgend welchen "aktiven" Stellen der Sonne Bündel spontaner negativer Strahlung ausgehen, aber nur bei günstiger Konstellation die Erde treffen und dann infolge ihrer geringen Steifigkeit hauptsächlich in den Polargegenden intensive Lichterscheinungen hervorrufen; dass aber die feldgetriebene positive Strahlung (in erster Linie wohl H-Kerne) *gleichmässig*, also mit geringerer Stromdichte, von der *ganzen* Sonnenoberfläche emittiert wird, daher immer zur Erde gelangt und dann bei ihrer grösseren Steifigkeit schwache, jedoch bis in niedere Breiten reichende Lichterscheinungen in der Atmosphäre erzeugt. Auch als Erreger einer sekundären γ-Strahlung (sehr durchdringenden Strahlung in der Atmosphäre) käme sie eventuell in Betracht.

Ferner ist zu berücksichtigen, dass von der Sonne ausgehende

Bündel spontaner Strahlen unter günstigen Umständen im Magnetfelde eines Planeten abgelenkt und dann durch die elektrostatischen Kräfte zur entgegengesetzt geladenen Sonne zurückgetrieben werden können; hierdurch wird die Ladungsbilanz der Sonne gestört und die Emission der feldgetriebenen Strahlen verändert. Die vielfach vermuteten "*Reflexwirkungen*"[9] der Planeten, die sich in Periodizitäten der Sonnenaktivität äussern, welche mit den Perioden der Planeten übereinstimmen, würden so einer physikalischen Erklärung näher gerückt.

Schliesslich seien noch einige numerische Resultate abgeleitet. Aus den direkt beobachteten Daten schliesst Störmer[10] bei den häufigsten Nordlichtformen auf eine erregende negative Strahlung, bei der das Produkt $H\rho$ von der Grössenordnung 700Γ. cm ist. Entsprechend der Tabelle in Abschnitt 2 folgt daraus abgerundet ein Wert $\beta=0.4$ und $P=80$ stat. Einh. Nehmen wir H-Kerne als hauptsächliche Träger der feldgetriebenen positiven Strahlung an, so folgt aus $\beta=0.4$ der Wert $\Pi=280000$ stat. Einh. und nach Gleichung (11) P_0 nahezu gleich gross. Aus P_0 berechnet sich, dass die Anfangsgeschwindigkeit der spontanen Strahlen zwischen $(1-10^{-4})$ und $(1-10^{-5})$ liegt. Für die positiven Strahlen hat bei $\beta=0.4$ das Produkt $H\rho$ den Wert $1.3\text{x}10^6\Gamma$. cm. Die positive Sonnenladung wird $Q_a=\Pi_a=$ rund $2\text{x}10^{16}$ stat. Einh. $=4\text{x}10^{25}$ Elementarquanten ($a=7\text{x}10^{10}$ cm gesetzt).

Man kann noch fragen, in welcher Zeit nach Beginn der Spontanstrahlung der stationäre Zustand praktisch erreicht wird. Ohne Kompensation durch positive Strahlen wäre die Endladung in der Zeit $\tau = \frac{Q_a}{I_1}$ erreicht; bei einer der vorhandenen Ladung *proportionalen* Ionenemission wäre $Q(t) = Q_a(1 - e^{-\frac{t}{\tau}})$, also z. B. $Q(t) = 0.95\, Q_a$ für $t=3\tau$. Tatsächlich erfolgt die Ionenemission nach Formel (10*b*) proportionel zu $V^{\frac{3}{2}}$, bezw. $Q^{\frac{3}{2}}$, ist also kleiner als eben angenommen. Die Zeit, nach welcher 95% der Endladung erreicht werden, ist daher grösser als τ, kleiner als 3τ, somit von der Grössenordnung 2τ. Soll dies z. B. in rund 22 Stunden $=80000$ sec erreicht werden, so muss $I = \frac{4\text{x}10^{25}\ \text{Elementarquanten}}{4\text{x}10^4\ \ \text{Sekunden}} = 10^{21}$ sein. Dem entspricht eine Emission von nur $\frac{1}{60}$ pro cm² und sec für die positiven Ionen und von 17 β-Strahlen pro cm² und sec für die spontane Strahlung, falls 1 Promille der Sonnenoberfläche als "aktiv" angenommen wird. Bei stärkerer Emission erfolgt die Herstellung des stationären Zustandes entsprechend rascher.

[9] Vergl. insbesondere L. A. BAUER, *Terr. Mag.*, **26**, 1921, pp. 40, 65-66, und 113-115.

[10] C. STÖRMER, *Geofys. Publ.* **1**, Nr. 5, Kristiania, 1921.

ZUSAMMENFASSUNG.

1. Es werden kurz die beobachteten Erscheinungen besprochen, die zu Hypothesen über die Existenz von korpuskularen kosmischen Strahlungen geführt haben, und die Wichtigkeit betont, die theoretischen Konsequenzen bezüglich des *Ladungszustandes* der emittierenden Weltkörper abzuleiten

2. Die Bestimmungsmerkmale korpuskularer Strahlen werden besprochen, speziell das "*Strahlpotential*" P, das als Quotient der kinetischen Energie und der elektrischen Ladung eines Teilchens definiert ist, sowie die *magnetische Ablenkbarkeit*. Eine Tabelle zur Berechnung dieser Grössen bei verschiedenen Geschwindigkeiten ist beigefügt.

3. Die stationäre Ladung einer Kugel, die spontan Korpuskularstrahlen ins umgebende Vakuum aussendet, wird berechnet. Sie ist *grösser* als das Produkt Pa aus Strahlpotential P und Kugelradius a und steigt mit der Intensität der Emission an. Die emittierten Teilchen werden dabei in einer Entfernung A zur Umkehr gebracht; der Wert von A wird ebenfalls berechnet. Numerische Beispiele für den Mond als supponierte Strahlenquelle werden beigefügt.

4. Die stationäre Ladung bei gleichzeitiger spontaner Emission von positiven und negativen Korpuskularstrahlen wird berechnet.

5. Analoge Rechnungen werden durchgeführt unter der Annahme, dass eine in der Oberfläche stark *ionisierte* Kugel eine spontane Strahlung und daher infolge ihrer Aufladung eine kompensierende feldgetriebene Ionenstrahlung aussende. Im stationären Zustande sind in grosser Entfernung dann *positive und negative* Strahlen von *gleicher* mittlerer *Intensität* und *gleicher Geschwindigkeit* vorhanden.

Die Resultate werden auf die Verhältnisse bei der *Sonne* angewendet und einige numerische Beispiele berechnet.

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ON THE SECULAR VARIATION OF THE MAGNETIC DECLINATION IN EKATERINBURG AND SIBERIA.

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Using as a basis the magnetic observations made by Dr. A. Smirnow in 1900, 1901, and 1909, and those in 1916, by the author of the present paper, as well as the observations at the Ekaterinburg Observatory, it is found that the magnetic needle reached recently in Siberia its maximum eastern declination and that it has begun its reverse movement towards the west.

At Ekaterinburg, the north end of the needle, since 1761, when the first determinations were made, until the year 1916, has moved constantly towards the east with a mean annual change of about four minutes. In 1761 the value of the declination was 0°50′E; in 1916, 11°03.′8 E. For the year 1917, however, the annual mean value as obtained from the hourly observations at the Observatory, amounted to 11°03.′7 E and for 1918, 11°03.′4 E. Accordingly, the needle remained stationary during 1916-1917, and in the following year moved 0.′3 towards the west. It may be expected, therefore, that it will now continue to move toward the west.[1]

The reverse movement of the magnetic needle began earlier in Siberia than at Ekaterinburg, as may be seen from the following data. Among the points at which the author made observations in 1916, there were four at which Smirnow had observed in 1901. These values, together with those obtained at Ekaterinburg, afford the following comparison:

TABLE 1

Station	*Easterly Declination* 1901.5 ° ′	1916.5 ° ′	*Annual Change* ′
Ekaterinburg	10 08. 6	11 03. 8	3. 7 E.
Petropavlovsk	12 26. 0	13 00. 1	2. 3 E.
Tartarskaja	12 06. 7	12 25. 8	1. 3 E.
Narym[2]	14 31. 7	14 47. 0	1. 0 E.
Mariinsk	11 16. 0	11 02. 7	0. 9 W.

The magnetic needle, accordingly, during the period 1901-1916, or for the epoch 1909, moved, in general, towards the east, though with varying speed. In the west the movement was more rapid than in the east. At Mariinsk, however, where the movement of the magnetic needle was likewise previously easterly, the westerly movement began about 1909. There must, consequently, have been a point between Tatarskaja and Mariinsk, where the needle

[1] The mean annual value of the declination at the Observatory for 1919 was 11°02.′8; for 1920 11°01.′9, and for 1921, 11°01.′5.

[2] Smirnow observed at Narym in 1900, and found the declination to be 14°30.′7 E; one minute has been added to his value to refer it to the year 1901.

stood still in the epoch referred to. By interpolation, the geographic coordinates of this place are found to be $\phi = 55°.8$ N; $\lambda = 82°.9$ E of Gr. There must also have been such a point on the line joining Mariinsk and Narym, probably about 57°.5 N and 84°.8 E.

That the declination was easterly at Mariinsk before 1909 is clear from D. A. Smirnow's paper, entitled "Die magnetischen Elemente auf der Linie von Warschau bis Vladivostok nach den Beobachtungen von 1901, 1904, und 1909." (Bulletin de l'Académie Impériale des Sciences de St.-Pétersbourg, 1910). On the last page of this work Smirnow compares the observations which he made at the same stations in 1901.5 and 1909.5. From these data are obtained the following annual changes which may be considered as applying to the epoch 1905.5:

TABLE 2

Station	*Annual change of declination 1905.5 (1901.5-1909.5)*
	′
Ekaterinburg.......	4. 5 E.
Petropavlovsk.......	3. 5 E.
Tomsk.............	2. 6 E.
Krasnojarsk........	0. 9 E.
Irkutsk............	1. 5 W.

This table gives a representation of the secular change in declination, similar to that shown in the foregoing table. Here also the change in declination is greater in the west than in the east. There is a difference, however, in that the place at which the needle stood still in the year 1905 was between Krasnojarsk and Irkutsk, that is, farther towards the east, than in 1909. By interpolation, we obtain for this place the coordinates, $\phi = 54°.6$ N.; $\lambda = 97°.2$ E.

We have found, then, that the magnetic needle ceased its easterly movement in 1905.5 at $\phi = 54°.6$ N and $\lambda = 97°.2$ E; in 1909.0 at $\phi = 55°.8$ N and $\lambda = 82°.9$ E and at $\phi = 57°.5$ N and $\lambda = 84°.8$ E, and in 1917.0 at $\phi = 56°.8$ N and $\lambda = 60°.6$ E.

The positions, at which the magnetic needle came to a stop, have accordingly moved gradually from east to west. The rate of this movement as obtained from the data for 1905.5 and 1917.0 is 3.2 degrees of longitude per year.

From the data for the year 1909, in combination with those for 1905, the annual motion is 4°.2 and 3°.7, while in combination with those for 1917, 2°.8 and 3°.0, respectively. In round numbers, then, the annual retrograde movement of the magnetic needle has amounted to 3 degrees of longitude.

In the application of this value it must be noted that it is perhaps dependent on geographical latitude, a fact which seems to be indicated by the two values for 1909. At any rate, there can be no doubt but that the magnetic needle will soon assume also in Europe, a westerly motion, just as is at present the case from Irkutsk to Ekaterinburg.

LETTERS TO EDITOR

PROVISIONAL SUN-SPOT NUMBERS FOR JANUARY TO JUNE, 1922.

Day	Jan.	Feb.	Mar.	Apr.	May	Jun.
1	..	0	109	26	38	7
2	0	12	127	29	31	0
3	0?	0	122	..	27	0
4	7	..	118	18	..	0
5	..	..	119	17	12	0
6	..	17	112	19	13	0
7	28	42	108	15	10	8
8	..	31	..	7	10	7
9	..	28	..	..	7	7
10	26	34	..	0	0	0
11	22	51	88	0	0	..
12	24	75	97	0	0	23
13	8?	63	79	0	..	17
14	14	39	53	0	0	16
15	..	26	28	0	0	16
16	17	..	16	..	0	10
17	..	13	16	..	0	9
18	7	10	18	..	0	..
19	..	16	11	0	0	0
20	..	7	0	0	0	0
21	..	8	..	..	0	9
22	..	..	..	7	0	7
23	..	8	..	10	0	7
24	0	17	..	17	7	7
25	..	24	38	25	8	7
26	0	36	27?	..	7	..
27	..	..	32	..	9	0
28	..	84	34	14	7	0
29	0	..	32	15	8	0
30	0	..	28	31	13	0
31	..	..	28	..	16	..
Means	10.2	27.9	60.0	11.4	7.7	5.8

A. WOLFER.

[1] For previous table, see *Terr. Mag.*, **26**, 135-136, 1921.

THE MAGNETIC CHARACTER OF THE YEAR 1921

The annual review of the "Caractère magnétique de chaque jour" for 1921 has been drawn up in the same manner as the preceding years. Forty observatories contributed to the quarterly reviews, 38 of them having sent complete data.

Table II of the annual review, containing the mean character of each day and each month, the list of "calm days" and the days recommended for reproduction, is reprinted here.[1]

G. VAN DIJK.

1921 TABLE SHOWING THE MAGNETIC CHARACTER FOR THE YEAR 1921

DATES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	MEAN
JANUARY	0.9	0.2	0.3	0.8	0.7	0.3	0.4	0.2	0.8	1.0	0.3	0.6	0.1	0.2	0.8	0.7	1.4	0.7	0.4	0.7	0.6	0.2	0.3	0.9	0.3	0.7	0.3	0.4	0.3	0.2	0.8	0.54
FEBRUARY	0.9	0.9	0.2	0.4	1.2	0.9	0.4	0.1	0.1	0.3	0.3	0.1	0.9	0.8	0.2	0.1	0.8	0.5	0.9	0.6	0.8	0.4	0.1	0.3	0.4	0.4	0.4	0.8				0.51
MARCH	1.0	0.9	0.6	0.3	0.1	0.2	0.3	0.1	0.9	1.0	0.3	0.6	0.2	0.9	1.3	1.0	0.2	0.3	0.1	0.1	1.4	1.3	0.3	0.9	1.3	1.2	1.3	0.7	1.2	0.8	0.2	0.68
APRIL	0.2	0.1	0.8	0.1	0.1	0.3	0.1	0.6	0.8	0.8	0.6	1.2	1.6	1.0	0.8	0.6	0.4	1.4	1.2	1.0	1.2	0.9	0.8	0.4	0.3	0.1	0.1	0.6	1.7	0.5		0.67
MAY	0.4	0.2	0.8	0.8	0.0	0.1	0.0	0.6	0.9	0.7	0.4	1.4	1.9	2.0	2.0	2.0	1.6	0.9	1.6	1.8	1.3	0.8	0.6	0.3	0.1	0.4	0.6	0.8	0.6	0.1	0.2	0.83
JUNE	0.5	0.4	0.8	1.0	0.1	1.1	0.8	1.2	1.0	0.9	0.4	0.2	0.4	0.9	0.2	0.4	0.6	0.1	0.2	0.6	0.4	0.8	0.9	0.4	0.1	0.7	0.3	0.3	0.7	0.3		0.55
JULY	0.5	0.1	0.2	0.7	0.1	0.7	1.0	1.0	1.2	0.4	0.1	0.5	0.7	0.7	0.9	1.0	0.3	0.3	0.7	0.6	0.1	0.6	0.8	0.4	0.1	0.6	0.4	0.6	0.7	0.7	0.2	0.54
AUGUST	0.0	0.7	1.2	0.9	1.1	1.1	0.8	0.7	0.2	0.3	1.0	0.5	0.2	0.6	1.0	1.0	0.7	0.1	0.1	0.3	0.5	0.2	0.1	0.2	0.0	1.1	0.9	0.2	0.0	1.2	0.8	0.58
SEPTEMBER	0.2	1.8	0.7	0.8	0.4	0.1	0.7	1.1	0.6	0.3	0.1	0.0	0.1	0.2	0.4	0.6	0.2	0.5	0.6	0.1	0.5	0.2	1.1	0.0	0.0	0.0	0.2	1.4	1.5	0.7		0.50
OCTOBER	0.9	0.3	0.2	0.8	1.0	0.8	1.0	1.9	1.0	0.6	1.4	1.1	0.2	0.5	0.6	0.1	0.1	0.1	0.1	0.4	1.1	0.6	0.4	0.5	0.2	0.2	1.0	0.9	0.8	0.2	0.9	0.63
NOVEMBER	0.7	0.0	0.1	0.0	1.0	1.3	0.7	0.7	0.7	1.0	0.1	0.2	0.8	0.7	0.4	1.6	1.7	1.2	1.0	0.5	0.8	0.7	1.1	0.5	0.4	0.2	0.1	0.3	0.0	0.1		0.62
DECEMBER	0.2	0.7	0.7	0.3	0.1	0.0	0.0	0.2	0.3	0.6	0.8	1.4	1.6	0.8	0.6	1.3	1.0	0.5	0.1	0.0	0.0	0.9	1.0	0.7	0.1	0.8	0.9	1.7	1.3	0.8	0.4	0.65

CALM DAYS

JANUARY	2,	8,	13,	14,	22.	FEBRUARY	8,	9,	12,	16,	23.	MARCH	5,	8,	17,	19,	20.
APRIL	4,	5,	7,	26,	27.	MAY	5,	6,	7,	25,	30.	JUNE	5,	15,	18,	19,	25.
JULY	2,	11,	18,	21,	25.	AUGUST	1,	9,	23,	25,	29.	SEPTEMBER	11,	12,	13,	24,	25.
OCTOBER	3,	16,	17,	18,	19.	NOVEMBER	2,	3,	4,	27,	29.	DECEMBER	6,	7,	19,	20,	21.

DAYS RECOMMENDED FOR REPRODUCTION

**May 13; May 15.

*March 21; April 29; May 14; May 16; September 2; November 17.

[1] For previous table, namely for 1920, see *Terr. Mag.*, **26**, 33, 1921.

PERIODICITY OF ACTIVITY IN TERRESTRIAL MAGNETISM.

Having been myself recently engaged in a discussion[1] of the 27-day "period" in magnetic disturbance, I read with interest Dr. G. Angenheister's paper on "Periodicity" in your recent issue.[2] With some of his conclusions my own investigations are in harmony, but others of his conclusions seem to me hardly warranted by the facts. I shall presently explain my reasons for dissent, employing for the purpose the data in the accompanying table, but a few preliminary remarks are desirable on the nature of the international "character" figures of which Dr. Angenheister and I have both made considerable use in our investigations.

As is, I think, well known to all who have considered these figures closely that while they discriminate admirably between the days of a single month, they suffer from the drawback that the significance possessed by the same numeral in different seasons is not the same. In a quiet year the figure 1.8, for example, connotes usually less disturbance than it does in a disturbed year. The years 1911-14, which contain a number of the "great" storms in Angenheister's Tables 1 and 2, *l. c.* pp. 64, 65, were, on the whole, very quiet years, and some of the storms of those years to which "character" figures of 1.8 or 1.9 were assigned were quite ordinary storms.

Another important point is that the international day commences at Greenwich midnight, and—at least in Europe—the Greenwich night hours are much more disturbed than the day hours. In most cases, even of short storms, the morning hours of the second day are highly disturbed, as well as the evening hours of the first day. It follows that in most cases high "character" figures are not isolated, but occur on two and sometimes more successive days. The higher of the successive "character" figures will presumably, as a rule, fall to the day which contains the C. G. of the disturbance; but even if such were always the case it would not tell us whether the height of the disturbance occurred in the morning or the evening. Supposing the first of two storms to culminate in the morning hours of day n, while the second storm culminates in the evening hours of day $n+26$, we get an apparent 26-day interval; while if the first storm culminates in the evening hours of day n, and the second in the morning hours of day $n+28$, the apparent interval is 28 days. In both cases, if we were able to fix the period of culmination, we might obtain 27 days for the interval. Thus the interval between successive storms of a series *may be* decidedly less variable than might be inferred from a study of the international "character" figures. Similar considerations apply to the intervals which Dr. Angenheister obtains when he uses the times of commencement of storms, as was in fact done in Mr.

[1] *Roy. Soc. Proc.* A., Vol. 101, p. 368.

[2] *Terrestrial Magnetism*, Vol. 27, p. 57.

Maunder's papers, which did so much to establish the 27-day "period." It is only when storms possess "sudden commencements" (or Sc's) that a very exact commencing time can be assigned, and even then the length of the storm, and the interval from the Sc to the principal movements, are very variable.

The conclusions drawn by Angenheister to which I here take exception are that there is an essential difference between greater and smaller storms, and that the 27-day period is confined to the latter, while "the greater magnetic storms, character 1.8-2.0, are repeated after integer multiples of 30 days" (*l. c.* p. 79).

A preliminary point to notice is that of the storms which Angenheister takes as the first of two series, A and B, showing the 30-day period, only one—the storm of September 25, 1909—was really outstanding. The storm of September 30, 1909, originating series A, was a comparatively commonplace one. Yet the "character" figures of the subsequent members of the two series appear closely similar. Coming now to the accompanying table, it embodies evidence—to which much could be added—that there is no fundamental difference between Angenheister's greater and lesser storms. It contains sequences[1] of storms in which the 27-day "period" seems clearly indicated, amongst which appear a number of the "great" storms included in Angenheister's Tables 1 and 2. The last two figures of the year follow the date of the month, Aug. 29 (09), for example, signifying August 29, 1909. When these figures are omitted, the year is the same as for the previous storm. The second column gives the international "character" figure, and the third column the interval between the storm given in the same line and the previous storm of the series. Only intervals of from 26 to 28 days are included.

The last two cases in the table were not considered by Angenheister. They are included to show that even a day of the extreme international figure 2.0 can be a member of a 27-day sequence. It may be explained that the mean "character" figure for a month averages about 0.6, and that "character" 1.3 implies very considerable disturbance in all months.

Some doubt may be entertained whether the disturbance of September 30, 1909,—the fundamental disturbance of Angenheister's series A—was a member of a 27-day series; but there seems no reasonable doubt of this in the case of the storm of September 25, 1909, and the other "great" storms of Angenheister which appear in my table. The dates of these Angenheister storms are in Italics. It will be seen that two of the sequences in my table each include two of Angenheister's "great" storms, and that these storms may occupy any position from first to last in the sequence. As a matter of fact, a considerable majority of the "great" storms in Tables 1 and 2 can be arranged as members of ordinary 27-day sequences. Under these circumstances it seems very improbable

[1]The possibility of "accident" playing a part in all such sequences must be conceded.

that there can be any essential difference in the place of origin of the greater and lesser storms such as Angenheister supposes.

To me a most surprising thing is that Angenheister seems really to have recognized himself that some of his "great" storms were members of 27-day sequences, because he can hardly have failed to notice the identity of several of the storms in his Tables 1 and 2 with storms which he gives in his Table 7, p. 71, which is apparently intended to illustrate the existence of the 27-day "period" in what he calls "the small storms" discussed in his Section F. The dates in my table and Angenheister's Table 7 do not always appear identical, but that arises from Angenheister's having used in that table the times of commencement as given in the Porto Rico list.

Whilst large storms are often members of apparent 27-day sequences, I do not recall an instance in which a really outstanding storm such as those of September 25, 1909, and May 14-15, 1921, was followed after a 27-day (or 30-day) interval by a storm of like magnitude.

C. CHREE.

TABLE 1.

Date	"Character"	Interval (Days)	Date	"Character"	Interval (Days)	Date	"Character"	Interval (Days)
Aug. 29 (09)	1.4		*Sept. 17 (12)*	1.8		Mch. 3 (16)	1.2	
Sept. 25	2.0	27	Oct. 14	1.6	27	Mch. 29	1.7	26
Oct. 23	1.7	28	Nov. 10	1.2	27	*Apr. 25*	1.9	27
			Dec. 7	1.4	27	May 22	1.7	27
Sept. 3 (09)	1.2		Jan. 3 (13)	1.4	27			
Sept. 30	1.8	27	Jan. 30	1.3	27	Dec. 16 (17)	2.0	
						Jan. 12 (18)	1.3	27
Dec. 28 (10)	1.5		Jan. 18 (13)	1.3				
Jan. 24 (11)	1.7	27	Feb. 14	1.6	27	Sept. 19 (18)	1.4	
Feb. 21	1.8	28	Mch 14	1.6	28	Oct. 16	2.0	27
Mch 20	1.9	27	*Apr. 9*	1.9	26	Nov. 12	1.7	27
Apr. 16	1.7	27	May 5	1.4	26	Dec. 8	2.0	26
			June 1	1.4	27			
July 28 (11)	1.6							
Aug. 23	1.8	26	Aug. 26 (15)	1.6				
Sept. 20	1.7	28	*Sept. 23*	1.8	28			
Oct. 18	1.4	28	Oct. 19	1.6	26			
Nov. 13	1.7	26	Nov. 16	1.7	28			
Dec. 11	1.9	28						

EARTHQUAKE RECORDS, WATHEROO MAGNETOGRAMS, OCTOBER 1921-JUNE 1922

The particulars of these records of earthquakes noted on the magnetograms of the Watheroo Magnetic Observatory, Western Australia, are given in the following tables. Table 1 shows also the times of the phases obtained on the seismograph at Perth according to the data supplied by Government Astronomer Curlewis.

TABLE 1.—*Earthquake records for October 10 and November 11, 1921.*

Date 1921	Magnetic record				Seismograph record	
	Element	Greenw. mean time Beginning	Greenw. mean time Ending	Remarks	Phase	Greenwich mean time
		h m	h m			h m s
Oct. 10	Declination.	2 13	2 34	Slight broaden-	P(?)	2 13 06.9
	Hor. Int....	2 13	2 39	ing of the traces	L(?)	2 19 12.9
	Vertical Int.	2 19	2 36	for all.........	....	....
Nov. 11	Declination.	18 45	19 01	Slight broaden-	P	18 43 56.6
	Hor. Int....	18 44	18 56	ing...........	(?)	18 46 00.5
	Vertical Int.	18 52	18 59(?)	Slight blurring..	L	18 50 10.4

TABLE 2.—*Earthquake records, January-May 1922.*

Date 1922	Phase	Greenwich mean time Hor. Int.	Greenwich mean time Decl'n	Greenwich mean time Vert'l Int.	Apparent maximum amplitude in hor. int.
		h m	h m	h m	mm
Jan. 1	Begin	12 34	.. ..	.. ..	Small
	End	12 30	.. ..	.. ..	
12	Begin	14 33	14 33	14 34	1.8
	End	14 38	14 38	14 39	
19	Begin	22 12	22 12	22 15	3.5
	End	22 33	22 25	22 27	
20	Begin	7 09	7 08		1.1
	End	7 18	7 15	Indistinct	
Feb. 5	Begin	3 47	3 48	.. ..	....
	End	3 51	3 54	.. ..	....
Feb. 5	Begin	18 06	.. ..	.. ..	(Doubtful as an
	End	Uncertain	.. ..	.. ..	earthquake record)
Feb. 9	Begin	16 55	Indistinct	Indistinct	....
	End	17 03	Indistinct	Indistinct	....
May 9	Begin	13 56	13 56	Indistinct	0.9
	End	14 09	14 09		
23	Begin	4 54	.. ..	.. ..	1.4
	End	5 01			

Mr. H. B. Curlewis, government astronomer of Western Australia, states that there was no apparent earthquake record on the

seismograph at Perth on May 23. He reports earthquake records on May 9, 11, and 12, the last being a very fine one; there are no evidences of earthquake records for May 11 and 12 on the magnetograms obtained at Watheroo.

June 8 and 29, 1922.—There were two possible earthquake records on the magnetograms centering at approximately June 8, 7^h 48^m Greenwich mean time, and June 29, 20^h 21^m Greenwich mean time. The government astronomer of Western Australia writes that, because of light trouble, no records were obtained from the seismograph at Perth on either of these dates.

G. R. WAIT, *observer-in-charge.*

AURORAL OBSERVATIONS AT HIGH RIVER, ALBERTA, CANADA, DECEMBER 28, 1921.

1^h A. M.—Two curtains observed; largest runs from N. W. to E., another below it extends from nearly North to N. E., latter is very bright at the W. end *i. e.* N., which appears to be bright because the curtain is running nearly away from the observer and hence more light is observed looking along the curtain than in looking through it. I have observed the same effect before, but I think it was the E. end that seemed to be in line with the eye. It was narrower on the E. end.

7^h45^m P. M.—Faint curtain observed, center nearly N.

9^h00^m P. M.—Faint arch low down, center N. E.

OWEN BRYANT.

NOTES

9. *Principal Magnetic Storms at Cheltenham Magnetic Observatory, January to June 1922.*[1]

Greenwich Mean Time		Range		
Beginning	Ending	Decl'n	Hor'l Int.	Vert'l Int.
$^{h\ m}$ Apr. 21, 22 ..	$^{h\ m}$ Apr. 22, 12 ..	′ 27.5	γ 186	γ 201

10. *Secular Magnetic Changes in the United States and Local Magnetic Disturbances.*—In the United States Coast and Geodetic Survey Bulletin No. 86, July 31, 1922, it is stated that according to recent repeat observations "the rate of secular change has varied so much recently that values (of the magnetic declination) carried from 1915 are in some cases not dependable." A publication entitled "The Declination in the United States for 1920," by D. L. Hazard, will soon be issued.

According to the same bulletin: 1. W. W. Merrymon, after standardizing his instruments at the Cheltenham observatory, proceeded to Birmingham, Alabama, and took up the investigation of locating iron ore by magnetic methods in co-operation with the Bureau of Mines. 2. The Commanding Officer of the steamer *Explorer* has made an investigation of a considerable area of local disturbance in Chilkoot Inlet, near Skagway, Alaska; the existence of this local disturbance has long been known, as it is in the main channel which is followed by vessels going to Skagway, but no accurate survey has heretofore been made.

11. *Magnetic Resurvey of Japan.*—Under date of July 16, 1922, Professor Tanakadate writes as follows: "We are now repeating the magnetic survey with the new electromagnetic instruments designed by Dr. Watanabe and communicated to the Rome meeting. Three parties have been sent out, one is now in Korea, another in Bonin Islands, and another in Sakhalin. They each carry the Kew magnetometer in addition to the electromagnetic one in order to compare the two methods at several stations. The stations will not be so numerous as in the previous surveys, but we hope to conclude the work in as short a time as possible in order to eliminate the effect of secular variation."

12. *Local Magnetic Disturbances and Secular Changes in the Bermudas.*—Messrs. H. W. Fisk and J. T. Howard, of the Department of Terrestrial Magnetism, returned from the Bermudas to Washington, September 26, after several months' successful investigation of local magnetic disturbances and secular changes. A number of the Department's stations, where magnetic observations had been made by Mr. Fisk in 1907 and by the *Carnegie* staff in 1910, were reoccupied.

[1] Communicated by E. LESTER JONES, Director, U. S. Coast and Geodetic Survey; GEO. HARTNELL, observer-in-charge. Lat. 30° 44′.0 N; Long. 76° 50.′5 or $5^h\ 07^m.4$ West of Greenwich.

13. *Magnetic observations, Amundsen Arctic Expedition, 1922.*—Dr. H. U. Sverdrup, in charge of the scientific work of the Expedition, mailed magnetic records to the Department of Terrestrial Magnetism, when the *Maud* on July 20, 1922 was at Deering, Kotzebue Sound, Alaska, in order to land Captain Amundsen for his proposed airplane flight from Alaska across the polar area, Kain-ge-skon, Siberia, the magnetic station of 1920 and 1921, was re-occupied on June 30, 1922. After landing Captain Amundsen, the *Maud* was to try to get as far north as the ice-conditions permitted. During the drift of the *Maud* there will be 8 men in all: Wisting, captain; Dr. Sverdrup and his Swede assistant in the scientific work, Neslingren; 2 engineers; one aviator; one sailor and all-round man; and one native cabin-boy.

14. *Return of MacMillan Baffin Land Expedition.*—The Expedition, under the leadership of Dr. Donald MacMillan, with whom the Department of Terrestrial Magnetism had cooperated, returned on September 12 to Wiscasset, Maine, the home port of the Expedition's vessel, the *Bowdoin*. Besides making important contributions to biology, ethnology, geology, meteorology, and tides, the Expedition succeeded in establishing a completely-equipped magnetic observatory at the winter-quarters, on the southwest coast of Baffin Land; this observatory was kept in successful operation from the end of October, 1921, until June 15, 1922, when it was necessary to dismount the instruments for the homeward voyage. During the greater part of this period continuous records of atmospheric-electric variations (potential gradient) were also obtained. The observatory was in charge of R. H. Goddard, an observer of the Department of Terrestrial Magnetism. Mr. G. Dawson Howell, a member of the Expedition, also made magnetic observations on various sledge trips in Baffin Land. Instead of returning aboard the *Bowdoin* he took advantage of the opportunity to travel from Lake Harbor, Baffin Land, on board the Hudson's Bay steamer and thus made magnetic observations at the various Hudson's Bay posts along Hudson Bay and along the Labrador coast.

15. *Watheroo Magnetic Observatory, Samoa Observatory, and Eclipse Magnetic Observations, September 1922.*—After the conclusion of the meetings of the International Geodetic and Geophysical Union and of the International Astronomical Union at Rome, Dr. Louis A. Bauer sailed from Marseilles on May 19 for Western Australia and New Zealand. Arriving at Perth on June 15, an inspection trip was made to the Magnetic Observatory at Watheroo, Western Australia, about 120 miles north of Perth. This observatory, operated by the Department of Terrestrial Magnetism, is almost antipodal to the magnetic observatory of the United States Coast and Geodetic Survey at Cheltenham, Maryland. Arrangements were completed for continuous observations of earth currents at the Watheroo Observatory. This year, also, the instruments are being installed for recording continuously the variations in the electric condition of the atmosphere. Thus, by the end of the present year, the Watheroo Magnetic Observatory will be the most completely equipped of its kind in the Southern Hemisphere.

While in Australia, the arrangements were completed by Dr. Bauer for the special magnetic and electric observations during the solar eclipse of September 21, 1922. Within the belt of totality, besides the astronomical observations, there will be made magnetic observations in accordance with the plan proposed by Bauer and Fleming (*Terr. Mag.*, vol. 27, pp. 83-85) at five well-distributed sta-

tions by the various expeditions. (On September 23 a cablegram was received from Mr. Coleman regarding successful eclipse magnetic observations made at Coongoola, Queensland, a station inside the belt of totality; see also Note 21.)

On July 4-5, Dr. Bauer attended at Wellington a specially-called meeting of the Samoa Observatory Honorary Board of Advice regarding matters pertaining to the continued operation of the Samoa Observatory at Apia, under the joint auspices of New Zealand, the British Admiralty and the Carnegie Institution of Washington.

En route to San Francisco, Dr. Bauer met at Rarotonga D. G. Coleman, observer of the Department of Terrestrial Magnetism, who has been re-occupying a number of the stations on the islands of the Pacific Ocean, and in New Zealand and Australia, where magnetic observations have been made by the Department in previous years. Mr. Coleman was then to proceed, via New Zealand, to the selected eclipse station at Coongoola, Queensland.

16. *"Erda" Aktiengesellschaft für wissenschaftliche Erderforschung, Göttingen, Germany.*—According to several pamphlets received, this appears to be a joint stock company, which in view of its purpose, is called "an institute for practical or applied geophysics." Its prime purpose is to place at the disposal of industry both theoretical knowledge and instrumental equipment for operations of a geophysical nature. Among the operations which, upon application, will be undertaken by the institute, are the following: Magnetic observations to determine the distribution of the magnetic elements and their local anomalies; electric measurements of natural and industrial earth currents; determination of the propagation of electric currents and electric (Hertzian) waves in the interior of the Earth; atmospheric-electric observations, etc.

17. *Journal for applied geophysics.*—Announcement has been received from the editor, Dr. Richard Ambronn, of the publication by the firm Gebrüder Bornträger, Berlin, of a new journal, to be called "Zeitschrift für angewandte Geophysik." The first issue has come to hand.

18. *International Meteorological Committee.*—The English report of the meeting at London in September, 1921 has been published as M. O. 248, Air Ministry, Meteorological Office. The following officers constitute the Bureau of the Committee, which consists at present of 16 directors of national meteorological institutes: Sir Napier Shaw, *president;* Professor E. van Everdingen, *vice-president,* and Director Th. Hesselberg, *secretary.* The members of the *Commission for Terrestrial Magnetism and Atmospheric Electricity* are: A. Angot, *president;* E. van Everdingen, *secretary;* T. Banachiewicz, L. A. Bauer, V. Carlheim-Gyllensköld, A. Ferraz de Carvalho, S. Chapman, C. Chree, J. Jaumotte, O. Krogness, A. Crichton Mitchell, G. Melander, L. Palazzo, C. Ryder, Napier Shaw, G. C. Simpson, Frederic Stupart, A. Wolfer.

19. *Personalia.*—*Prince Albert of Monaco,* distinguished for his oceanographical studies, died at Paris on June 27, at the age of seventy-five years. Dr. *G. Angenheister* has accepted a position on the staff of the Geodetic Institute at Potsdam, Germany. Rev. *A. L. Cortie,* director of Stonyhurst College Observatory, received an honorary doctorate at the recent celebrations of the seven-hundredth anniversary of the University of Padua. Colonel *E. Delcambre* has been appointed director of the French Meteorological Office. Dr. *B. Meyermann,* formerly director of the Observatory of Tsingtau, has been appointed to succeed

Prof. *Ambronn*, who has retired from the directorship of the Göttingen Observatory. Prof. *R. Spitaler* is giving a course in atmospheric electricity at the University of Prag, during the summer semester 1922. Dr. *W. F. G. Swann* has resigned his professorship of physics at the University of Minnesota and has accepted a similar post at the University of Chicago. Dr. *Louis A. Bauer* has been made a "corresponding member" of the Société de Géographie de Lisbon, Portugal. Prof. *J. A. Pollock*, well known for his investigation of the ions of the atmosphere, died on May 24, after a short illness, at the age of fifty-seven years. Dr. *S. K. Banerji* was appointed in April director of the Bombay and Alibag observatories.

20. *Chauveau's Atmospheric Electricity.*[1]—Workers in atmospheric electricity will welcome an extended treatise on atmospheric electricity by M. Chauveau. From the preface we learn that the completed work will consist of three principal subdivisions devoted, respectively, to (a) historical introduction, (b) the electric field of the atmosphere, and (c) the ionization of the atmosphere. Only the first fascicle, about 100 pages, has thus far appeared. It is devoted entirely to the historical introduction, which, in three chapters, traces the development of ideas and methods during three well-defined periods: the first (1750 to about 1860), from Franklin to Peltier; the second (1860 to 1899), from William Thomson to Exner and his pupils; and the third or modern period, in which the names of Elster and Geitel and of Ebert are predominant. That the author's treatment of the subject is unusually detailed is obvious from the above outline. Accordingly one finds here many matters of historical interest that are not included in other general works on atmospheric electricity, together with numerous references to original sources.

21. *Magnetic Character of day of solar eclipse, September 21, 1922.*—According to information received from the Director of the United States Coast and Geodetic Survey, the magnetic character of the days at the time of the eclipse, as judged by the magnetograms of the Cheltenham Magnetic Observatory, Maryland, the times given being Greenwich civil mean time, was as follows: September 20 was quiet until 18^h (6 P. M.), when H (horizontal intensity) and Z (vertical intensity) were slightly disturbed, values averaging about normal, this disturbed condition lasting until September 21, 7^h. Between September 21, 0^h and 1^h, there was a downward bend in D (declination) of some 13 minutes. After September 21, 7^h, the magnetic elements were quiet and normal. (Since the solar eclipse began on September 21, $2^h\,04^m$, G. M. T., and ended at $7^h\,16^m$, there was a slight magnetic disturbance, which began 8 hours before the eclipse and continued throughout the eclipse period. This cosmic disturbance may possibly complicate the detection of the small effect to be ascribed to the eclipse; however, before reaching a definite conclusion, it will be best to await the reports from the eclipse expeditions and from observatories in other regions of the Earth.)

[1] B. CHAUVEAU, *Électricité Atmosphérique*, premier fascicule, introduction historique. Paris, Gaston Doin, Éditeur, 1922.

LIST OF RECENT PUBLICATIONS

A. Terrestrial and Cosmical Magnetism.

ANTIPOLO OBSERVATORY. Hourly results of the observations made at the Magnetic Observatory of Antipolo, near Manila P. I., during the calendar year 1918. (Part IV of the annual report of the Weather Bureau for the year 1918.) Manila, Bureau of Printing, 1921, 47 pp. 29 cm.

AZORES. Résumé d'observations. Service Météorologique des Açôres. Années 1913 à 1920. Lisbonne, Imprimerie Nationale, 1914-1921, 17x32 cm. ca. 20 pp. [Each résumé contains the values of the three magnetic elements at the S. Miguel Magnetic Observatory during the year to which the résumé applies. These values are the means of observations made at different times in the course of the year.]

BANGKOK. Report on the operations of the Royal Survey Department of the Army for the year 1919-1920. Bangkok, Bangkok Daily Mail, 1921 (88 with 3 maps). 34 cm. (On pages 8-10 are given the results of magnetic observations 1905-1920).

BARNETT, S. J. A sine galvanometer for determining in absolute measure the horizontal intensity of the earth's magnetic field. Abstr. Physic. Rev., Lancaster, Pa., Ser. 2, v. 19, No. 4, April, 1922 (425-427). [Published in full in Vol. IV, Researches of Department of Terrestrial Magnetism, pp. 373-394, 1921.]

BAUER, L. A., J. A FLEMING, H. W. FISK, AND W. J. PETERS. Land magnetic observations 1914-1920 and special reports. Researches of the Department of Terrestrial Magnetism, Volume IV. Washington, D. C., Carnegie Inst., Pub. No. 175 (Vol. IV), 1921 (v + 475 with 9 pls. and 17 figs.). 30 cm. (See Abstract, *Terr. Mag.*, vol. 27, pp. 86-87, 1922.]

BAUER, L. A., AND J. A. FLEMING. Results of comparisons of instruments for measuring the earth's magnetic elements. Abstr. Physic. Rev., Lancaster, Pa., Ser. 2, v. 19, No. 4, April, 1922 (427-428). [See fuller publication by J. A. Fleming in Vol. IV, Researches of Department of Terrestrial Magnetism.]

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BUREAU DES LONGITUDES. Annuaire pour l'an 1922. Paris, Gauthier-Villars et Cie (632 + A.6 + B.29 + C.25 + D.18 + E.5 + F.70). [Contains magnetic chart of France for the epoch January 1, 1911, also table giving values of the magnetic declination in Tunis, Algeria, and Morocco reduced to the same epoch.]

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B. Terrestrial and Cosmical Electricity

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VOLUME XXVII NUMBER 4

TERRESTRIAL MAGNETISM

AND

ATMOSPHERIC ELECTRICITY

An International Quarterly Journal

December, 1922

Conducted by
LOUIS A. BAUER
With the Co-operation of Eminent Investigators.

CONTENTS

PUBLISHED FOR
THE JOHNS HOPKINS PRESS, BALTIMORE
THE ABINGDON PRESS, 420 PLUM ST., CINCINNATI, O.
THREE DOLLARS AND FIFTY CENTS A YEAR SINGLE NUMBERS, ONE DOLLAR

WHELDON & WESLEY, Ltd., 28 Essex St., Strand, LONDON, W. C., 2
THE ABINGDON PRESS (Cash Subscription) 420 Plum St., CINCINNATI
MAYER & MÜLLER Prinz Louis-Ferdinand Str BERLIN

Entered as second-class matter at the Post-office at Cincinnati

Terrestrial Magnetism
and
Atmospheric Electricity

VOLUME XXVII DECEMBER, 1922 NO. 4

ON THE METHODOLOGY OF FINDING AND REPRESENTING THE DISTRIBUTION OF A NATURAL ELEMENT OVER A CERTAIN REGION OF THE EARTH'S SURFACE, WITH SPECIAL REFERENCE TO TERRESTRIAL MAGNETISM.*

BY BORIS WEINBERG.

1. *The problem.* Let E denote the value of a natural element at a given point and a given time, *e. g.*, the temperature, humidity or pressure of the air, the magnetic force, the geological formation, etc. We shall restrict ourselves here to dealing with elements which can be measured quantitatively and the variations of which are continuous both in space and with time. Furthermore, if we consider only the values of the natural element at the surface of the globe, we may write

$$E = \Phi\ (\phi,\ \lambda,\ t) \tag{1}$$

where ϕ and λ are the latitude and longitude of a point at the surface of the globe and t is the time. Our problem is then to find and represent this function for the whole globe or a part of it by means of observations of E, taken at different points and at different times.

The ideal solution would be to express E as an analytical function of ϕ, λ, and t, thus making it possible to calculate the value of E for any point on the globe at any time. However, this ideal is not attainable owing to the great variability of all the natural elements. Therefore, the problem is regarded as solved for a given region and interval of time, if with the aid of tables or graphical representations we can predict the approximate values of E at different points within this region for any moment of this interval. As an example of a satisfactory solution, we may mention charts of the distribution of the magnetic elements accompanied by indications or charts of the annual changes.

* Based on two long manuscript articles, dealing with the general method of representing the distribution of some geophysical element and accompanied by 13 figures. The abstract was kindly prepared for the Journal by Dr. H. U. Sverdrup, and revised by the author.—*Ed.*

1

2. *The real variation of a natural element with time.* Let us first discuss only the question of the changes of E at a given point with the time. If the element can be registered, then the registrations will give us the *real* values of E for each moment t, only smoothed by the inertia of the registering instrument. The real changes of E, thus obtained, can be regarded as composed of:

I. Secular changes;
II. Cyclic changes of definite periods (or "regular periodic");
III. Cyclic changes of variable periods (or "irregular periodic");
IV. Rapidly varying non-cyclic changes (or "accidental aperiodic");
V. Slowly varying non-cyclic changes (or "systematic aperiodic"),

or in analytical form:

$$\begin{aligned} E_{\phi_1\lambda_1} = {} & \mathrm{F}_T(t) + \mathrm{f}_{T_1}(t) + \mathrm{f}_{T_2}(t) + \dots\dots\dots \mathrm{f}_{T_n}(t) + \\ & \phi_{T_1}(t) + \phi_{T_2}(t) + \dots\dots\dots\dots + \phi_{T_n}(t) + \\ & \alpha_1(t) + \alpha_2(t) + \dots\dots\dots\dots + \alpha_n(t) + \\ & \beta_1(t) + \beta_2(t) + \dots\dots\dots\dots + \beta_n(t) \end{aligned} \tag{2}$$

Such a decomposition is more or less arbitrary: the only group which without any doubt can be differentiated from the others is the second which contains the regular periodic changes.

If continuous registrations of E are not at hand, but only values of E at different moments, then the question may arise as to how to find the *real* value of E for any moment between two observations. Theoretically, this problem cannot be solved, but the practical solution is to interpolate in some way or other between the observed values. This implies, however, certain mathematical assumptions which are enumerated and treated in detail in the article and of which the most common are that the element is changing uniformly between two successive observations, or that the irregular aperiodic changes are small. To be sure that such is the case, the author recommends making, instead of a single reading, several readings during an interval of time which is small if compared with the intervals between such separate groups of readings. If such is not the case, then any attempt to find the real value of E between two observations must fail. The interpolation may be made graphically by taking the values sought, from a curve drawn through the points determined by observations, or arithmetically by means of some formula for interpolation. Both methods are, however, deficient as they introduce discontinuities in the change of the

element: the graphical, because it is not possible to draw a curve which, when magnified, will not show numerous breaks; the arithmetical, because no interpolation formula can take full account of the curvature of the curve, representing the real change of the element. Usually an interpolation-formula, which takes account of the second differences, will be sufficient. Let us introduce the following notation:

E_i, the value of E at the time $t = t_i$;
T, the constant time difference between two observations;
$E(t)$, the value of E at the time t where $t_{i+1} > t > t_i$;
$\Delta E_i = E_{i+1} - E_i$;
$\Delta^2 E_i = \Delta E_{i+1} - \Delta E_i = E_{i+2} - 2 E_{i+1} + E_i$.

After an analysis of the correspondence between the mathematical assumptions mentioned above and the different formulas for interpolation, the author reaches the conclusion that the most satisfactory formula is:

$$E(t) = E_i + \frac{t-t_i}{T} \Delta E_i + \frac{(t-t_i)(t-t_i-T)}{2T^2} \frac{\Delta^2 E_i + \Delta^2 E_{i-1}}{2} \quad (3)$$

3–5. *The normal change of an element with the time.* The real change of an element being either unobtainable or too complicated for practical or theoretical purposes, the problem of finding the real change is often replaced by the problem of finding the ***normal*** change of the element. Since there is no general agreement on the conception of normal change, we shall have to define it in such a way that our definition will agree with the most usual interpretations. By normal change we will understand the change in E free from all irregular periodic or aperiodic accidental or systematic changes. Of the components of E, we keep only the first two, the secular and the regular periodic, thus writing:

$$E_{norm} = \mathrm{F}_T(t) + \mathrm{f}_{T_1}(t) + \mathrm{f}_{T_2}(t) + \ldots\ldots \mathrm{f}_{T_n}(t) \quad (4)$$

Each separate term on the right side of this equation may also be called a normal change, for instance, "normal secular change," "normal diurnal change," and so on.

If E has been registered continuously, the process of finding the normal change usually consists in taking the values of E for equidistant intervals of t from the graphs and from these values to compute the separate periodic functions $f_1, f_2, \ldots f_n$, starting with the one which has the shortest period. If the registrations show great aperiodic changes, it is advantageous to obtain the mean

values of E for the time-intervals either by summation, or graphical integration, and to coordinate these values with the mean time of the interval.

If only separate values of the element are known, the computation of the normal change will be much more uncertain, chiefly on account of the presence of values which represent abnormal conditions. These may sometimes be rejected, but there is no safe criterion for the rejection of "discordant" observations, although many have been proposed. Accordingly, the determination of the normal change is often arbitrary because the result, to a great extent, depends upon where the limit for rejection has been drawn.

6. *The smoothed change of an element with the time.* In order to weaken, in the first place, the influence of systematic aperiodic changes of not very long duration, the method of smoothing the results of observation is used. We can define what we mean by the smoothed value of E by the equation:

$$E_{smooth} = F(t) + f_1(t) + f_2(t) + \ldots\ldots + f_n(t) + r[\phi(t) + \alpha(t) + \beta(t)] \qquad (5)$$

where $0 < r < 1$

The process of smoothing consists in substituting for each observed value E_p, a smoothed value E'_p derived from the value E_p and the preceding and following values:

$$E'_p = l_0 E_p + l_1 (E_{p-1} + E_{p+1}) + l_2 (E_{p-2} + E_{p+2}) + \ldots + l_k (E_{p-k} + E_{p+k}) \qquad (6)$$

where $l_0, l_1 \ldots\ldots l_k$ are numerical constants, which are subject to the condition

$$l_0 + 2(l_1 + l_2 + \ldots\ldots + l_k) = 1 \qquad (7)$$

In order that the values E'_p may actually deserve the name of smoothed values, the following requirement must be fulfilled: It must be possible to find a function

$$E(t) = E(t, E_{p-k} \ldots E_p \ldots E_{p+k}) \qquad (8)$$

which is continuous, preserves its form for each of the intervals between the moments

$$t_{p-k} \ldots\ldots t_p \ldots\ldots t_{p+k},$$

gives identical values for these transitory moments, and the mean value of which shall be equal to the corresponding smoothed value, that is:

$$\int_{t_p - \frac{1}{2}T}^{t_p + \frac{1}{2}T} E(t)\, dt = E'_p\, T \tag{9}$$

The smoothing can be made graphically or arithmetically. The graphical smoothing, which is of a rather arbitrary character, consists in drawing a smooth curve, not through the points E_p, t_p in the (E, t) diagram, but near them and taking for the values of E'_p, the values of the ordinates of the curve.

The arithmetical smoothing consists in computing the values E'_p by means of fixed values $l_0, l_1 \ldots . l_k$. The same process may be repeated and a second set of smoothed values E''_p computed, and so on. The usual formula for smoothing is the one in which all l's have the same value and k is usually taken equal to 1 or 2, as, for example, $k = 1$:

$$E' = \frac{1}{3}(E_{p-1} + E_p + E_{p+1}) \tag{10}$$

But these formulas do not seem to satisfy the idea of smoothing as expressed in equations (8) and (9); they do not produce any function $E(t)$, which gives a smooth change of E.

The following method of smoothing may be preferable. Let us regard one observation made at the time t_p as represented by the rectangle $ABCD$, having for altitude an ordinate $OP = E_p$ and for base, a time interval $AD = T$ (see Fig. 1). The use of formula (10) for smoothing implies that we replace this rectangle by the rectangle $abcd$, the base of which is equal to $3T$ and the height equal to $\frac{1}{3} E_p$. The adjacent rectangles, which are not indicated in the figure, are treated in the same way and the smoothed value E'_p is the sum of the three rectangle parts over the base $AD = T$. Now, instead of flattening the rectangle $ABCD$ into another rectangle, we will transform it into an area limited by the curve

$$E = \frac{hE_p}{\sqrt{\pi}\, T}\, e^{-\frac{h^2 (t - t_p)^2}{T^2}} \tag{11}$$

and determine the coefficient h so that the area, bounded by the curve and the ordinates AB and CD will be one-half of the area $ABCD$, which gives us

$$h = 0.8538\ldots \tag{12}$$

The method here suggested can also be described in other words. The curve defined by (11) gives the probability according to Gauss's law for E, assuming the value E_p within the different time intervals

$T_{p-k} \ldots T_{p+k}$, and by means of (12), we arbitrarily fix this probability within the interval $T_p = AD$ at 0.5. The probabilities for E, assuming the value E_p within the time intervals T_{p-1} etc., can easily be found by evaluation of the integral $\int e^{-x^2} dx$. We denote the probabilities by W_1, W_2 .... and find

$$W_1 = 0.2286\ldots;\quad W_2 = 0.0210\ldots;\quad W_3 = 0.004\ldots \tag{13}$$

These values multiplied by E_p evidently represent the areas limited by the curve (11) and the ordinates DC, dc, etc. The smoothed value E'_p corresponding to the time t_p can be regarded as the sum of the areas over the base AD, limited by the curve (11) and the corresponding curves for E_{p-2}, E_{p-1}, etc.

$$E'_p = 0.02\,E_{p-2} + 0.23\,E_{p-1} + 0.5\,E_p + 0.23\,E_{p+1} + 0.02\,E_{p+2} \tag{14}$$

Equation (14) gives us separated smoothed values. However, it is evident that we can easily determine a function $E(t)$ which gives us continuous smoothed values, thus fulfilling the condition (9). The function $E(t)$ is simply the sum of the ordinates of the curves E corresponding to any value of t

$$E(t) = \sum_{i=p-k}^{i=p+k} \frac{h\,E_i}{\sqrt{\pi}\,T}\; e^{-\frac{h^2(t-t_i)^2}{T^2}} \tag{15}$$

where it is usually sufficient to take $k=2$; see (13). The formulas here developed have given very satisfactory results in practice.

The final result of the computations made to determine the real, normal or smoothed change of an element with time may be represented by a graph, a table, or an empiric formula. These different representations have both advantages and disadvantages, treated in detail in the article.

7. *The interval of time between separate observations and the limit of precision necessary for finding the change of an element with time.* The author gives here certain suggestions concerning these questions.

8. *The representation of the change of an element with time.*

9. *The representation of the distribution of an element over a certain region.* Let us suppose that we know the values of an element E for a number of points (ϕ. λ) of a certain region for a given moment $t=t_0$, either from simultaneous observations or from observations reduced to the same epoch, the observation of an element at *all* the points over a certain area being physically impossible.

The distribution of the element is generally so complicated that its analytical representation is impossible. The tabular representation usually has the form of a table with two entrances, or a set of tables for each of which, one of the independent variables, ϕ or λ, has a constant value. Three different graphical representations may be mentioned:

a. A series of curves showing, for instance, the variation of the element with longitude for different values of latitude;
b. Maps with shaded regions, in which the value of the element lies within certain limits;
c. Maps with isolines, i. e., lines along which the element has a constant value.

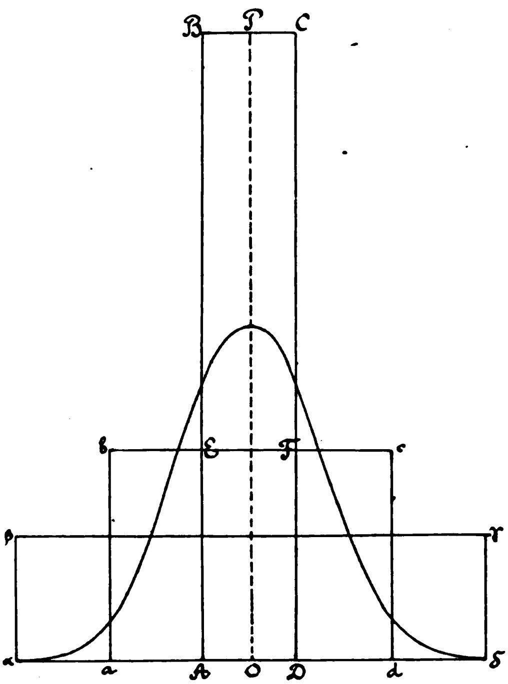

FIG. 1.

The last method is the most familiar, but the defects of this representation become obvious, when we discuss how to find the value of the element represented by the isolines at any point not on the isolines. If the isolines are running smoothly and their distances for equidistant values of the element are varying slowly, then we may find the value at the point by linear interpolation. However,

if the shape of the isolines and their mutual distances are irregular, the graphical interpolation will depend on the direction of the straight line along which we shall interpolate and the differences between the estimated value at the point may reach 20 or 30 per cent of the difference between the values of the element at two consecutive lines.

The same difficulties arise when we try to interpolate from a table with double entrance (ϕ and λ). The usual formulas for interpolation do not take account of second differences or, in other words, the formulas for determining the value E at a point ϕ, λ for which

$$\phi_0 < \phi < \phi_1; \quad \lambda_0 < \lambda < \lambda_1$$

contain only the values E_{00}, E_{01}, E_{10} and E_{11} corresponding to the four adjacent points, ϕ_0 λ_0, etc.; but even in this case there can be four different formulas according to the values: $\frac{E_{10} - E_{00}}{\Delta \phi}$ or $\frac{E_{11} - E_{01}}{\Delta \phi}$ and $\frac{E_{01} - E_{00}}{\Delta \lambda}$ or $\frac{E_{11} - E_{10}}{\Delta \lambda}$, which are attributed to the gradient of the element along the meridians and the parallels.

The author points out the incompatibility of the assumption of the linear change of these gradients and of the element itself, and gives the following formula for interpolation which contains some of the second differences:

$$\begin{aligned} E = E_{00} + & \frac{E_{10} - E_{00}}{\Delta \phi} (\phi - \phi_0) + \frac{E_{01} - E_{00}}{\Delta \lambda} (\lambda - \lambda_0) + \\ & \frac{E_{11} - E_{10} - E_{01} + F_{00}}{\Delta \phi \, \Delta \lambda} (\phi - \phi_0)\ (\lambda - \lambda_0) + \\ & \frac{E_{20} - 2\,E_{10} + E_{00}}{2\,\Delta \phi^2} (\phi - \phi_0)\ (\phi - \phi_1) + \\ & \frac{E_{02} - 2E_{01} + E_{00}}{2\,\Delta \lambda^2} (\lambda - \lambda_0)\ (\lambda - \lambda_1) \end{aligned} \tag{16}$$

It should be noted that the graphical, as well as the arithmetical, interpolation leads to a break in the continuity of the values of the gradient of the element; the graphical in crossing an isoline, the arithmetical in crossing a meridian or a parallel.

10. *The real distribution of an element over a certain region.*

11. *How to find the points of equal values of an element over a certain region.*

12. *The desirability of perfecting the method of finding the position of the points of equal value.*

13. *The most approximate distribution of stations in the survey of a certain region.*

14. *The problem of drawing the lines of equal value.* Having shown in paragraph 9 that the representation of an element over a certain region, neither by means of lines of equal values nor by a table, permits us to determine the value of the element at any point with a high degree of accuracy, the author shows the impossibility of solving even approximately the inverse problem, namely, that of finding the distribution of an element by means of observations made at isolated points. The first step in solving this problem is to find the position of the points of equal values, i. e., the points where the element has the selected equidistant values. The second step is to draw the lines of equal value. For the determination of the points there are—usually silently made—several assumptions, the most important of which is, that the element in the vicinity of a station varies proportionally with the distance from the station. However, a simple geometrical consideration shows that this assumption is generaly incorrect. The relation between the element E and the geographical coordinates ϕ and λ can be represented as a surface

$$z = f(x, y) \tag{17}$$

The above-mentioned assumption implies that this surface has a so-called conical point over the station, x_0 y_0, or that the surface itself is a plane. Another assumption, which is often made although also not expressed, and which is really a consequence of the first, is that if the element has the same value at two adjacent stations, then it has the same value on the straight line connecting these stations. A geometrical consideration shows that this assumption implies that the surface (17) is not only a linear surface but a cylinder. Therefore, the only case when both assumptions are fulfilled is the one when surface (17) is a plane.

To illustrate the methods by which these assumptions are used for finding the "isopoints," or points of equal values, we may take as an example the discussions of the results of the magnetic survey of a part of the Government of Petrograd, which have been made independently by M. A. Rykačev[1] and E. A. Kučinskij.[2] Rykačev simply determines the "isopoints" by interpolating between two adjacent stations, supposing that the element changes linearly

along the line connecting the two stations. Kučinskij uses another method. He combines not only adjacent stations but stations, the distance between which is less than three times the average distance between all stations, and determines much more numerous points of equal values by linear interpolation between such pairs of the stations. The different ways in which Rykačev and Kučinskij draw the "isolines" will be discussed later.

The author, in his investigations of the distribution of the elements of terrestrial magnetism in Siberia,[3] has used another method. The magnetic observations were usually made along certain routes which were divided into rectilinear parts. If the deflections from the straight line were noticeable, the observed values at the points nearest to the straight line were reduced to the line by means of an approximate value of the gradient of the element, obtained from a preliminary isolinic map. For the varation of the element along such a straight line, one of the following formulas was adopted:

$$E = E_0 + \alpha\,(\phi - \phi_0) \tag{18}$$

or

$$E = E_0 + \beta\,(\lambda - \lambda_0) \tag{19}$$

where E_0, α and β were computed by means of the method of least squares. The position of the "isopoints" on these straight lines could then be computed. If the stations were scattered irregularly, or over a limited part of the region, the linear expression

$$E = E_0 + \alpha\,(\phi - \phi_0) + \beta\,(\lambda - \lambda_0) \tag{20}$$

was adopted, and the constants in this equation were determined by means of the method of least squares.

A comparison between the three methods for finding the "isopoints" carried out in the case of the above-mentioned observations in the Government of Petrograd, show that, if the stations are 20 or 30 km. apart, the position of the real values of the declination (accurate to 1′) cannot be found with any higher degree of accuracy than 2 km. in a quiet region, and this limit amounts easily to 6 km. in a region where the "anomalies" of declination are of the order of 15′ to 20′.

Another method of finding the "isopoints" may also be suggested according to which the points derived from different combinations of stations receive different weights according to their distance from the nearest station. The weight may be indicated by representing the "isopoint" as a circle, the area of which is proportional

to the weight. This method is intermediate between those used by Rykačev and the author, and that used by Kučinskij.

The conclusion which may be drawn from these considerations is that the methods of finding the "isopoints" need a fundamental revision and perhaps ought to be made subject to a general agreement between scientists interested in the distribution of natural elements over the surface of the globe, in order to make possible a comparison of the results of different investigations.

In paragraph 13, the author deals with the problem of effecting a distribution of stations such as to make possible the precise computation of the value of an element at an intermediate point and, from considerations based on the theory of surfaces and on the solution of the problem of the number and form of differential parameters of a function of two independent variables, shows that the triangular disposition of the stations, besides other advantages which it has, for example, over the quadratic disposition, permits such a computation.

The "isopoints," the determination of which has been dealt with in paragraph 11, must be regarded as representing the *real* "isopoints." When now in paragraph 14 the author proceeds to the problem of drawing the "isolines," we meet with the question as to what kind of lines we seek. The real distribution of an element may be regarded as a sum of different terms:

$$\begin{aligned} E(\phi, \lambda) = {} & f_1(\phi, \lambda) + f_2(\phi, \lambda) + \ldots\ldots\ldots + f_n(\phi, \lambda) \\ & + \phi_1(\phi, \lambda) + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ & + \alpha_1(\phi, \lambda) + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ & + \beta_1(\phi, \lambda) + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \end{aligned} \tag{21}$$

corresponding to expression (2) for the different changes of an element with time, only that the term representing the secular variation is missing because the surface of the globe is limited. The terms $f_1, f_2 \ldots\ldots$ the author calls the *telluric distribution;* the terms $\phi_1, \phi_2 \ldots\ldots$, the *irregular periodic local disturbances;* the terms $\alpha_1, \alpha_2 \ldots\ldots$ and $\beta_1, \beta_2 \ldots\ldots$, the *aperiodic regional disturbances,* respectively. The *normal telluric* distribution is defined as the sum of the terms $f_1, f_2 \ldots$, the *normal regional distribution,* as the sum of the terms $f_1, f_2 \ldots$ and $\beta_1, \beta_2 \ldots$, and the *smoothed distribution,* as:

$$\begin{aligned} E_{smooth} = {} & f_1(\phi, \lambda) + f_2(\phi, \lambda) + \ldots\ldots\ldots f_n(\phi, \lambda) \\ & + r\,[\,\phi(\phi, \lambda) + \alpha(\phi, \lambda) + \beta(\phi, \lambda)\,] \end{aligned} \tag{22}$$

where $0 < r < 1$

Before describing the methods used by the author in his investigations, we will mention the methods used by Rykačev and Kučinskij for tracing the "isolines." Rykačev simply connects the "isopoints" by straight lines and gets thus a broken "isoline." Kučinskij obtains by his method numerous "isopoints" lying in strips. He first draws a smooth line in the middle of this strip and then draws a final wave-like line through the points lying half way between his smooth curve and the "isopoints." No attention is paid to the weight of the "isopoint."

The following method was used by the author in determining the smoothed distribution of the magnetic elements reduced to the epoch 1910.[3] The "isopoints" were determined by means of equations (18) to (20) and their positions were plotted on maps. They were distributed in strips resembling parabolic curves, hence the equations:

$$\left.\begin{aligned} \phi &= \phi_0 + \gamma\ (\lambda - \lambda_0) + \delta\ (\lambda - \lambda_0)^2 \\ \lambda &= \lambda_0 + \gamma'\ (\phi - \phi_0) + \delta'\ (\phi - \phi_0)^2 \end{aligned}\right\} \qquad (23)$$

were introduced to represent the "isolines." The coefficients in these equations were determined by means of the method of least squares. The deviations in longitude and latitude of the "isopoints" from the "isolines" (22) could be regarded as partly due to errors of observation, partly to errors in reduction to 1910, and partly to local disturbances. Hence, it seemed appropriate to apply a method of smoothing to them. After using the method of smoothing described in paragraph 6, a second set of points of intersections of the "isolines" with the meridians and parallels was found. This second set showed regular variations between these points of intersection, so the next step was to express it by means of the following equations, again using the method of least squares:

$$\left.\begin{aligned} \phi &= \phi_0 + \eta\ (E - E_0) + \epsilon\ (E - E_0)^2 \\ \lambda &= \lambda_0 + \eta'(E - E_0) + \epsilon'\ (E - E_0)^2 \end{aligned}\right\} \qquad (24)$$

The last step consisted in smoothing the deviations of the second set from the values computed by (24). The fourth set thus obtained was regarded as the final values for the intersection of the smoothed "isolines" with the meridians and parallels. No attempt was máde to express the result in analytical form.

In order to compare the system of lines derived by this method with that drawn by Rykačev and Kučinskij, the method here described was also applied to the observations treated by them, and

the lines were also represented by an analytical expression of the second degree in relation to $\phi - \phi_0$ and $\lambda - \lambda_0$. The result was that the mean deviation of the observed values from the smoothed values computed by the author was slightly less than the mean deviation resulting from the "real" lines of equal values obtained in other ways.

The preference of the author's method was still more evident when he treated—also by different methods—the distribution of the vertical component in a case where the latter could be calculated for every point of the region (a field disturbed by some supposed ellipsoidal and cylindrical masses of given dimensions, orientations, positions and changes).

15-16. *The time interval between consecutive surveys, the density of stations and the accuracy of the observations.* Considering the great differences between the natural elements which are subject to observation, it is impossible to give any rules of general application. The selection of time-interval, density of stations and the limit of accuracy depend not only upon the changes of the element with time and space, but also upon the aim of the observations, e. g., whether the real, the normal, or the smoothed distribution of the element is sought. Some theoretical considerations may give help toward answering the questions here raised (cf. § 12). In most cases, however, the answer can only be found by experience, namely, by making "micro-surveys"—observations at several "points" of a "station."

17. *Finding and representation of the changes of the distribution of an element over a certain region.* We have until now dealt separately with the change with time and the distribution over a certain region, and have, in both cases, discriminated between real, normal and smoothed change or distribution. If we now consider both together we obtain nine different combinations, the real change of the real distribution, and so on. Generally one of these combinations is sought, namely the smoothed change of the smoothed distribution. The problem of finding this does not differ materially from the separate problems treated before, but is more complicated, because it deals with three independent variables. The practical solution of the problem consists in:

a. Organization of stations where the change of the element with time is observed continuously;

b. Surveys of the whole region which have to be repeated at certain intervals.

The observations can be treated according to the methods here described. The results can be represented by sets of tables or sets of maps accompanied by diagrams, giving the change with time at certain selected stations, etc. Charts of the annual change of an element are graphical representations of a peculiar type.

18. *The density of the stations and the precision of the measurement by the magnetic surveys.*

We shall try now to apply these general considerations to the particular case of a magnetic survey, with special reference to Asiatic Russia.

For populated regions with a sufficient number of permanent or temporary magnetic observatories or stations, real values of declination and inclination may be known with an accuracy of $\pm 2'$ and of horizontal intensity within about $\pm 10\gamma$. This limit is set by uncertainty as to reduction to a certain epoch and by errors of observation. However, it is not possible to find the real value of D at a point not coinciding with a point of observation within less than $\pm 5'$ even if the stations are about 20 km. apart (see paragraph 11).

If we consider the field observations made in regions thinly populated, where the means of transportation are very difficult, the maps deficient, and for which data regarding annual variations are few, it is no exaggeration to assume that the real value of D (declination) for a station, after reduction to the epoch, can be considered to be known only within some $\pm 10'$, of I (inclination) within $\pm 5'$ and of H (horizontal intensity) within $\pm 10\gamma$. For a point lying off one of the routes, the error of the interpolated "real" value of D can easy exceed some $20'-30'$, of I some $10'-15'$, and of H some $30-50\gamma$.

In such cases the use of instruments of high precision would be justified if after 20 to 30 years it would be possible to secure along the route of the expedition even a few repeat stations. For many regions—particularly for well-nigh half of the 86 per cent of the area of Siberia which is still entirely unexplored in respect to terrestrial mgnetism[4]—the realization of such fundamental stations is practically impossible. Besides, the determination of the annual change of one of the elements of terrestrial magnetism, deduced from the comparison of determination made now with a smaller precision but at a greater number of points (the author emphasizes again the idea of "micro-surveys") with the determinations which may be made in several points of the same district in 20 to 30 years, will be sufficiently trustworthy.

Therefore it is quite legitimate to ask the question whether it is possible to reduce the requirements usually made as to the instruments and to the methods used in field observations during the surveys in such inaccessible regions as, for instance, the greater part of Asiatic Russia? Is it not preferable to have determinations of a moderate precision than to have none at all? Positive answers to these questions would at once make possible magnetic surveys of many regions which must otherwise wait for several decades.

In this respect special attention deserves to be drawn to the words of L. A. Bauer in his general suggestions[5] to the observers of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington: "Local disturbances frequently exceed the diurnal-variaton correction. Hence, in disturbed regions, and if the time is limited, multiplicity of stations, rather than great accuracy at one station, must be the endeavor." Since only a great number of stations can give information regarding disturbances, and since in Siberia the time for observation is practically limited to the summer, the author forms L. A. Bauer's words thus: "Multiplicity of stations must be the endeavor, even at the expense of a certain lowering of the precision of the measurement."

In favor of such assertion, the author quotes one more consideration: It is practically impossible to find the real distribution, hence, the purpose of a magnetic survey—at least of the first survey of a region not yet visited by magneticians—must be to find the smoothed or even the normal regional distribution of magnetic elements, and for this purpose it is sufficient to have determinations of an inferior precision but, if possible, free from local influences. This consideration can be corroborated by the following table, which gives the values of the mean deviations of the values of D, I and H for the magnetic survey of Japan of 1913 from the "normal" distribution given by T. Nakano[6], computed by the author separately for the "normal" stations and for the "anomalous" stations, as well as for both kinds together.

TABLE 1.

Japan, 1913	$\triangle D$	$\triangle I$	$\triangle H$
	$'$	$'$	γ
Normal stations....	± 6.4	± 6.0	± 71
Anomalous stations.	± 35.5	± 34.6	± 286
All stations........	± 10.3	± 9.8	± 100

It may be noted that, assuming the average amount of the local disturbing force to be of the order of 200γ[7], the formulas which the author has deduced in the quoted paper give for $I = 49°$ and $H = 0.30$ c. g. s.,

$$\triangle D = \pm 12', \quad \triangle I = \pm 8', \quad \triangle H = \pm 100\gamma.$$

The reduction of the requirements to the precision of the observations, compared with the precision which can be obtained with a first-class instrument during a stay lasting not less than 8 hours, can be reached in three ways:

a. Abbreviation of the program of the observations at each station;
b. Simplification of the methods of the determinations;
c. Using instruments of another type.

If, as an example of a first-class instrument, we take the C. I. W. (Carnegie Institution of Washington) magnetometer-inductor, a full set of observations comprises:

a. Observations of the Sun;
b. Determination of the inclination;
c. Determination of the declination with a preliminary detorsion of the ribbon and with the inversion of the magnet;
d. Oscillations and torsion;
e. Deflections;
f. $=e$; $g=d$; $h=c$ (without detorsion); $i=d$; $j=a$.

If the interval of observation includes noon, the circummeridian observations of the Sun are added. If the time is limited, some points of this program have to be canceled.[8] Personally, the author recommends, as far as the items *c* to *h* and *j* of the program above are concerned, to sacrifice those in the following order: (1) detorsion, (2) determination of the torsion, (3) repeating of the inversion of the magnet by declination observations, (4) repeating of the deflections, (5) repeating of the oscillations, (6) deflections entirely, (7) inversion of the magnet entirely, (8) number of pointings on the Sun (4 and even 2 instead of 8), (9) pointings on the Sun and determinaton of the declination entirely, or oscillations entirely.

A considerable economy of time is attained when two observers are working simultaneously, and there is a separate astronomical theodolite and also a special stand with a horizontal circle for the magnetic house. Then it is possible to mount at once the earth-inductor, the galvanometer, the magnetometer, and the astronomical theodolite, the two latter being placed on one straight line with the chosen mark. The presence of a separate theodolite, be-

sides increasing the precision of the readings (from 1′ of the C. I. W. magnetometer to 10″ and 20″ of the Hildebrand's theodolite—small model—which the author usually takes with him on his trips), has a calming effect, in the case of a cloudy sky, on the observer, who is now sure that if the Sun appears even for a short time the station will not remain without determination of *D*. But even if the theodolite of the magnetometer has to be used for the observations of the Sun, a separate circle for the magnetometer is very useful. As an illustration, the author quotes the observations at Sunijarskoje in 1914, where, owing to the fact that on the steamboat his assistant, the late A. A. Belov, and himself had previously mounted the earth-inductor, the magnetic house and the galvanometer, they had succeeded during the 23-minute stop of the boat, in carrying the instruments to a sufficient distance from the steamer to make one pointing on the Sun and one on the mark, three settings of the earth-inductor, one pointing on the magnet, and one on the mark, and one series of observations of 150 oscillations, and to return to the steamer. The values of *D*, *I* and *H*, computed from these observations, gave quite satisfactory results when plotted on the isolinic charts.

Generally the author is of the opinion that the time of every forced stop caused by some unforeseen circumstance must be used for an extension of the above program, as well as to an increase of the number of the observations of each item of the program, or for repeating the observations at another point of the station, or for organizing variometric observations. But if the time of the stop is limited it is better to use it for the determination of two or even one element instead of the three, with the intention of determining at the followng station only the deficient elements, if the stop there also will be short, rather than to make no observations at all. In the practice of his seven expeditions, the author in several cases used a 15 to 20-minute stop of the steamboat for a determination of *D* and *H*, or of only *D*, or of only *I*, or of only *H*.

The determination of *H* can be simplified. The most important step in this direction would be attained if we could eliminate the use of the chronometers, which have to be transported very carefully. Indeed, the modern methods of preparing magnets, the magnetic moment of which decrease very slowly and regularly, make it possible to determine the magnetic moment only at the beginning and at the end of even comparatively long-lasting expeditions and of observing on the expedition either the deflections

only, or the oscillations only, with but an insignificant decrease of the precision of the result.

First steps in this direction were made by V. D. Dudeckij and the author by means of a stop-watch with a double pointer; one was running uninterruptedly, and the second stopped after a first pressing of the button, and at a second pressing of the button overtook the first pointer and went along together with it. The experiments gave quite satisfactory results. Furthermore, the author proceeded to the use of an ordinary watch, by means of which the observer noted the times after counting two seconds after the passage of the magnet. The errors in the notations of the time seldom exceed half a second. If we consider the unfavorable case, that the time of 5 oscillations is only 18 seconds, and that only 150 oscillations are observed, then in using a chronometer and assuming the mean error of the difference of the moments of the passage to be equal to 0.2 second, we obtain for the relative accuracy of the period the value $\frac{0.2}{360\sqrt{11}} = 0.00017$ of the period, that means of 0.03 per cent of H, and in using an ordinary watch, of 0.12 per cent H, e. g., about 25γ for the author's region of work, which may be considered as a sufficient precision.

If we limit outselves to a precision of this kind and agree to take observations of deflections only at the final stations of an expedition, the dimensions of the box containing the magnetometer can be considerably diminished. We do not need the deflection bar, nor the box for the deflecting magnet, nor the deflecting magnet itself; the suspension ribbon can be made shorter and also somewhat thicker, and therefore more solid, and hence the magnet house smaller.

It should be noted that, if in order to increase the number of stations very much, the precision is reduced to 20′ for D, 100γ for H, and 10′ for I, the instrumental equipment might be reduced to considerable simplicity and portability. The azimuth could be determined by observation of Polaris without any angle-measuring instrument, for instance, by means of two plumb-lines,[9] which allow finding the direction of the meridian within 10′ to 15′. The time-correction of the watch might then be found within 30 to 40 seconds by observing the passage of some known stars.

For the determination of D, a good declination needle could serve, especially when it is provided with a double top. For the determination of H and V (and hence of I) with a precision of 1/4 to

½ per cent of their values, the portable "deflectors" used in the navy could serve, giving the values of H and V by means of simple and rapid manipulations. Such a simplification of the method of field observations might extend our knowledge of the distribution of the magnetic elements to regions never before visited, not only by magneticians, but by any scientific investigator.

TOMSK, SIBERIA.

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3. B. P. WEINBERG: "On the distribution of magnetic inclination over Siberia," (prepared for press, 1919); B. P. Weinberg, "On the distribution of magnetic declination in Siberia," (prepared for press, 1920); B. P. Weinberg, "On the distribution of the horizontal component of terrestrial magnetic force in Siberia," (prepared for press, 1920). A summary of these papers will be given in an article entitled, "The normal distribution of terrestrial magnetism over Siberia in 1910."
4. B. P. WEINBERG: "A brief outline of the magnetic investigations of Siberia and their nearest problems and possibilities," Trans. of the assembly for organ. of the Inst. of explor. of Siberia, 2, 30-35, 1919.
5. L. A. BAUER: "Land Magnetic Observations, 1905-1910," Washington, 1918, p. 18.
6. See e. g. the discussion of the magnetic survey of Japan in 1913, by Nakano. T. NAKANO, "Reduction of the observed values of the magnetic elements to the epoch 1913.0 and to sea-level and deduction of their empirical expressions with a discussion of secular variation," Bull. Hydrogr. Office of I. Japan Navy, II, 63-186, 1918.
7. See BORIS WEINBERG: "On the secular variation of terrestrial magnetism in Siberia," Terr. Mag., 24, 71-75, 1919.
8. "Instruction for observations with the magnetic theodolite of Department of Terrestrial Magnetism of the Carnegie Institution of Washington," (Russ.), Tomsk, 31 pp., 1914.
9. *Cf.* N. D. PAVLOV: "The determination of the true meridian by sight," (Russ.), Omsk, 15 pp., with 2 charts (lith.), 1919.

COMMENTS ON WEINBERG'S SUGGESTIONS FOR FIELD WORK.[1]

By J. A. Fleming.

With modern instruments and reasonable control of secular variation and a scheme of observation arranged so as to aid in the elimination of diurnal variation, it seems assured that the values of the magnetic elements for a given epoch at stations where observations have once been made may be known with an accuracy approaching $\pm 2'$ in declination, D, and inclination, I, and with an accuracy of $\pm 0.001H$ in horizontal intensity, H, with the exception of stations in high magnetic latitudes where diurnal-variation corrections and reductions on account of magnetic storms are uncertain.[2] This should hold even in regions where there are relatively few stations. The real values at points intermediate between stations should be capable of interpolation with a precision not much less than above indicated *provided* no local disturbances exist. It is the practice of the Department of Terrestrial Magnetism, as indicated in our "General Directions for Magnetic Observations," to determine at each station, before carrying out the complete program of observations, whether there is any appreciable local disturbance, thus insuring that distribution and secular-variation stations may represent, as nearly as possible, normal values in the regions concerned. For regions where local disturbances are found to exist, provision is made for a greatly increased number of stations with a lower order of precision.

Multiplicity of relatively inaccurate observations in regions of known distribution, at practically the same expenditure of time and money, would be a mistake, particularly in view of the fact that the secular change, as shown by extensive experience, may not be extrapolated safely for many years. Secular-change data resulting from observations made at intervals of from 20 to 30 years, a procedure indicated as desirable by Weinberg, would not meet requirements.

The extensive experience of our observers in all parts of the world has shown that with the modern form of magnetometers difficulties of transportation can be successfully overcome. For surveys in regions of high magnetic latitude our work has been facilitated, with no great decrease in general accuracy, by the use of the dip circle with compass and telescope attachments, using Lloyd's method for the determination of total intensity, F, and inclination, I, with the restriction that loaded-dip and deflection observations should invariably be made at every station; with this universal instrument it is possible to secure observations for the determination of all three elements in a very short time.

Our practice is to take advantage of every opportunity offered to secure observations, even if only one element can be determined,

Concluded on page 168.

[1] *Cf. Terr. Mag.*, this article, pp. 150-155.

[2] Because of the different order of values of H at various stations, it is desirable to express the order of accuracy of observation in parts of H rather than in gammas, as Weinberg has done.

LATEST ANNUAL VALUES OF THE MAGNETIC ELEMENTS AT OBSERVATORIES.[1]

COMPILED BY J. A. FLEMING.

Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity Hor. (H)	Intensity Ver. (Z)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
Sodanklyä	67 22 N	26 39 E	1915	0 27.2 E	75 22.1 N	.12853	.49232[2]
			1916	0 34.6 E	75 25.0 N	.12806	.49222
Pavlovsk	59 41 N	30 29 E	1919	2 35.2 E	71 07.9 N	.16023	.46882
Sitka	57 03 N	135 20W	1920	30 28.2 E	74 22.1 N	.15574	.55663
Katharinenburg	56 50 N	60 38 E	1913	10 57.4 E	71 12.1 N	.17290	.50792
			1914	11 00.1 E	71 16.2 N	.17219	.50786
			1915	11 02.6 E	71 21.2 N	.17142	.50797
			1916	11 03.8 E	71 25.6 N	.17070	.50800
			1917	11 03.7 E	71 29.8 N	.17000	.50796
			1918	11 03.3 E	71 33.7 N	.16936	.50797
			1919	11 02.8 E	71 38.1 N	.16872	.50823
			1920	11 01.9 E	71 42.1 N	.16812	.50843
			1921	11 01.5 E	71 46.1 N	.16754	.50865
Rude Skov	55 51 N	12 27 E	1919	8 07.4W	68 58.2 N	.17144	.44592
			1920	7 57.2W	68 59.6 N	.17124	.44596
Kasan (n. site)	55 50 N	48 51 E	1914[3]	8 21.3 E	69 22.1 N	.17891	.47517
Esdalemuir	55 19 N	3 12W	1919	16 58.7W	69 39.5 N	.16713	.45084
Meanook	54 37 N	113 20W	1921	27 33.3 E	77 53.7 N	.12909	.60190
Stonyhurst	53 51 N	2 28W	1921	15 41.5W	68 43.0 N	.17315	.44449
Wilhelmsh'vn	53 32 N	8 09 E	1911	11 28.2W	67 30.7N[4]	.18110	.43747[5]
Potsdam	52 23 N	13 04 E	1921	7 18.9W	66 34.5 N	.18591	.42911
Seddin	52 17 N	13 01 E	1921	7 20.2W	66 31.5 N	.18629	.42896
Irkutsk	52 16 N	104 16 E	1909	1 51.3 E	70 33.5 N	.19860	.56265

[1]See tables for previous years in *Terr. Mag.*, vol. 4, p. 135; vol. 5, p. 128; vol. 8, p. 7; vol. 12, p. 175; vol. 16, p. 209; vol. 20, p. 131; vol. 22, p. 169; vol. 23, p. 191; vol. 25, p. 179; and vol. 26, p. 147.

[2]The value of Z for 1914 should read 0.49260 instead of 0.49238 as given on p. 147, *Terr. Mag.*, vol. 26.

[3]Values are means for first 4 and last 4 months only.

[4]Absolute values only.

[5]Computed from I and H; the same remark applies wherever values of Z were lacking in observatory publications.

Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity Hor. (H)	Intensity Ver. (Z)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
De Bilt	52 06 N	5 11 E	1921	11 13.6W	66 52.6 N	.18389	.43065
Valencia[6]	51 56 N	10 15W	1919	19 27.2W	68 06.1 N	.17842	.44385
Bochum	51 29 N	7 14 E	1921	10 10.4W	....	......	......
Greenwich	51 28 N	0 00	1920	14 08.6W	66 51.8 N	.18456	.43192
			1921	13 57.6W	66 52.0 N	.18449	.43183
Kew	51 28 N	0 19W	1919	14 40.9W	66 57.7 N	.18416	.43305
Uccle	50 48 N	4 21 E	1915	12 38.4W	66 01.2N[7]	.18989	......
Hermsdorf	50 46 N	16 14 E	1913	6 58.2W	....	......	......
Prague	50 05 N	14 25 E	1914	7 32.1W	....	......	......
			1915	7 24.2W	....	......	......
			1916	7 14.3W	....	......	......
			1917	7 05.3W	....	......	......
Cracow	50 04 N	19 58 E	1913	5 03.3W	64 18.4 N	......	......
Val Joyeux	48 49 N	2 01 E	1917	13 21.5W	64 41.2 N	.19690	.41629
			1918	13 12.4W	64 43.2 N	.19680	.41669
Munich	48 09 N	11 37 E	1911	9 23.8W	63 06.2 N	.20633	.40676
O'Gyalla (Pesth)	47 53 N	18 12 E	1915	5 50.1W	....	.20995	......
			1916	5 41.1W	....	.20966	......
			1917	5 31.0W	....	.20945	......
			1918	5 2[illegible].9W	....	.20917	......
Pola	44 52 N	13 51 E	1918	7 11.0W	60 09.0 N	.22113	.38533
Agincourt	43 47 N	79 16W	1921	6 50.6W	74 44.5 N	.15839	.58065
Tiflis	41 43 N	44 48 E	1913	3 09.1 E	56 51.1 N	.25217	.37612
Capodimonte	40 52 N	14 15 E	1911	8 05.5W	56 11.7 N	.24171	.36099
			1912	....	56 12.4 N	.24150	.36084
Ebro(Tortosa)	40 49 N	0 31 E	1921	11 49.1W	57 37.6 N	.23301	.36754
Coimbra	40 12 N	8 25W	1919	15 29.4W	58 25.0 N	.23075	.37538
Cheltenham	38 44 N	76 50W	1920	6 18.5W	70 55.4 N	.19118	.55285

[6]Means of 2 absolute values monthly.
[7]Mean of 2 to 4 absolute values each month for 10 months, January to October.

Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity Hor. (H)	Intensity Ver. (Z)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
San Miguel[8].. (Ponta Delgada)	37 46 N	25 39W	1913	19 53.2W	60 49.5 N	.23059	.41283
			1914	19 49.4W	60 46.2 N	.23063	.41216
			1915	19 53.2W	60 49.5 N	.23059	.41282
			1916	19 42.7W	60 39.1 N	.23072	.41033
			1917	19 39.2W	60 36.4 N	.23088	.40986
			1918	19 34.1W	60 32.7 N	.23090	.40886
			1919	19 30.4W	60 29.5 N	.23105	.40824
			1920	19 24.9W	60 26.0 N	.23123	.40759
San Fernando	36 28 N	6 12W	1919	14 08.5W	53 44.6N[9]	.25012	......
Kakioka.....	36 14 N	140 11 E	1914	5 12.9W	49 29.8 N	.29783	.34868
Tsingtau[10]....	36 04 N	120 19 E	1916	4 04.7W	52 07.1 N	.30842	.39644
			1917	4 07.0W	52 06.1 N	.30851	.39631
			1918	4 08.2W	52 06.9 N	.30827	.39621
			1919	4 09.9W	52 07.4 N	.30812	.39613
			1920	4 12.9W	52 07.0 N	.30817	.39610
Tucson......	32 15 N	110 50W	1919	13 47.8 E	59 27.0 N	.26940	.45644
			1920	13 48.0 E	59 27.6 N	.26910	.45611
Lukiapang...	31 19 N	121 02 E	1915	3 13.2W	45 32.1 N	.33212	.33839
			1916	3 16.0W	45 31.9 N	.33201	.33823
			1917	3 17.8W	45 31.5 N	.33201	.33815
			1918	3 18.8W	45 31.0 N	.33212	.33817
Dehra Dun...	30 19 N	78 03 E	1920	1 52.0 E	44 59.9 N	.32951	.32949
Helwan......	29 52 N	31 20 E	1914	2 09.2W	40 50.9 N	.30016	.25954
			1915	2 03.0W	40 54.8 N	.30012	.26009
			1916	1 53.7W	40 57.5 N	.29985	.26026
			1917	1 45.7W	41 01.9 N	.29963	.26076
Hongkong[11]...	22 18 N	114 10 E	1912	0 04.5W	30 56.3 N	.37206	.22302
			1913	0 06.5W	30 53.7 N	.37166	.22239
			1914	0 08.8W	30 53.5 N	.37184	.22247
			1915	0 11.7W	30 52.2 N	.37166	.22217
			1916	0 13.8W	30 51.8 N	.37144	.22198
			1917	0 16.3W	30 50.4 N	.37155	.22183
			1918	0 18.0W	30 48.3 N	.37151	.22150
			1919	0 19.8W	30 47.5 N	.37158	.22143
			1920	0 20.7W	30 46.4 N	.37174	.22137
			1921[12]	0 19.8W	30 45.8 N	.37295	.22199

[8]Means of absolute values as follows, the first figure indicating D and the second figure I and H observations: 1913, 49 and 41; 1914, 37 and 32; 1915, 18 and 12; 1916, 35 and 35; 1917, 44 and 44; 1918, 35 and 35; 1919, 44 and 44; 1920, 28 and 28.

[9]This value is the mean resulting from absolute observations with dip circle and two needles, the individual results showing great and irregular differences.

[10]Values are means from all hourly values.

[11]Values as finally adopted and differing in intensity from those previously published because of changes in distribution-coefficient.

[12]Absolute values at new hut for November and December only; to refer values in new hut to those in the old hut the following corrections must be applied: D, $+3'.0$; I, $-0'.8$; H, -0.00105; Z, -0.00074.

Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity Hor. (H)	Intensity Ver. (Z)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
Honolulu....	21 19 N	158 04W	1920	9 53.2 E	39 25.1 N	.28847	.23711
Toungoo.....	18 56 N	96 27 E	1920	0 23.7 E	23 07.7 N	.39114	.16707
Alibag.......	18 38 N	72 52 E	1920	0 20.2 E	24 54.7 N	.36922	.17147
			1921	0 15.9 E	24 59.5 N	.36956	.17226
Vieques......	18 09 N	65 27W	1919	3 39.9W	51 17.7 N	.27905	.34825
			1920	3 46.1W	51 22.7 N	.27827	.34831
Antipolo.....	14 36 N	121 10 E	1917	0 35.9 E	16 07.7 N	.38088	.11014
			1918	0 35.5 E	15 05.0 N	.38115	.10986
Kodaikánal...	10 14 N	77 28 E	1920	1 49.9W	4 36.1 N	.37787	.03042
Batavia-Buitenzorg.	6 11 S	106 49 E	1916	0 46.0 E	31 38.4 S	.36698	.22613
St. Paul de Loanda....	8 48 S	13 13 E	1910	16 12.3W	35 32.2 S	.20125	.14374
Apia[13]	13 48 S	171 46W	1921	10 10.7 E	30 03.8 S	.35265	.20412
Tananarivo...	18 55 S	47 32 E	1914	8 25.2W	53 37.9 S	.22484	.30532
Mauritius....	20 06 S	57 33 E	1919	10 10.4W	52 42.8 S	.23112	.30356
			1920	10 20.3W	52 40.1 S	.23093	.30278
Watheroo....	30 18 S	115 53 E	1921[14]	4 22.6W	63 57.7 S	.24848	.50860
Pilar.........	31 40 S	63 53W	1918	8 05.5 E	25 39.5 S	.25397	.12200
Toolangi.....	37 32 S	145 28 E	1920	8 00.8 E	67 55.1 S	.22874	.56384
Christchurch[15]	43 32 S	172 37 E	1902	16 15.1 E	67 40.8 S	.22694	.55277
			1903	16 18.3 E	67 42.3 S	.22669	.55286
			1904	16 21.8 E	67 44.1 S	.22644	.55307
			1905	16 25.4 E	67 45.8 S	.22628	.55348
			1910	16 37.6 E	67 54.8 S	.22515	.55485
			1913	16 44.0 E	67 58.2 S	.22449	.55478
			1914	16 44.8 E	67 59.8 S	.22414	.55465
			1920	17 01.7 E	68 09.2 S	.22261	.55525
N. Year's Isl .	54 39 S	64 09W	1916	16 02.4 E	49 39.4 S	.26771	.31520
Orcadas[16]....	60 43 S	44 47W	1912	4 46.5 E	54 26.0 S	.25343	.35442

[13] Formerly designated the Samoa Observatory.
[14] Means of absolute values determined weekly.
[15] Corrected values as finally published or values not previously given in *Terr. Mag.*
[16] Corrected values both for position and for magnetic elements.

ON THE NON-SIMULTANEITY OF MAGNETIC STORMS.

By Rev. Luis Rodés, S. J.

Dr. Bauer in a study based chiefly on data collected by Faris, reached the conclusion that "magnetic storms do not begin at precisely the same instant all over the Earth." The abruptly beginning ones, investigated by him, appeared to progress more often towards the east than towards the west, with a velocity such that it would require, on the average, about four minutes to encircle the Earth at the equator.[1]

I should like to call attention to the fact that in the case of five well-defined storms which occurred subsequent to those examined by Bauer, namely, those of January, February and May, 1919, March, 1920, and May, 1921, I have found a simultaneous beginning at Tortosa and at Honolulu, which lies 158 degrees to the west, within the limits of measurement. The photographic paper at Tortosa runs at the rate of 2.8 minutes to the millimeter and the base line is shown every hour by an electric lamp in connection with the astronomical clock, hence, I do not think we can be in error by a minute. The measures for each storm were accurately made by the writer, and the corresponding times of the beginning as registered at the other stations were kindly communicated to me by Col. E. Lester Jones, director of the U. S. Coast and Geodetic Survey, at Washington, and by Capt. R. L. Faris, acting director.[2]

Table 1 gives the times of beginning of 15 storms in comparison with the times registered at Tortosa. The storm of August 11, 1919, began simultaneously at Lukiapang, Tortosa and Porto Rico, a range of 186 degrees in longitude, while the other stations have apparently registered it progressively earlier.

The last two storms (March 22, 1920, and May 13, 1921) began very suddenly and simultaneously at Tortosa, Cheltenham, Tucson, Sitka and Honolulu, representing a range of 171 degrees.

[1] *Terr. Mag.*, vol. 15, 1910, pp. 221-232; R. L. FARIS, vol. 15, 1910, pp. 93-105; see also L. A. BAUER, vol. 15, 1910, pp. 9-20.

[2] I am indebted to Sir Frederic Stupart for the data of Agincourt; to Prof. J. M. Baldwin for those of Melbourne; to Mr. W. H. Cullum for those of Tucson, and to Rev. J. de Moidrey for information respecting Lukiapang.

It would seem probable that, as the time record has been more accurately kept during recent years, the results would indicate a simultaneous beginning all over the Earth. There are, nevertheless, some cases in which a propagation is strongly suspected. In such cases, which will be the first observatory to register the magnetic storm? I do not know of any answer to this question.

The author has tried a hypothesis which rests to some extent on facts. If a magnetic storm is due to the Earth's entering a cloud of electrical particles projected from the Sun, the case will be similar to that of the Earth's entering the Moon's shadow during an eclipse, and the storm will first be registered at those observatories which are nearer the "front meridian," as I have designated the one which, because of the Earth's rotation, happens to be foremost in direction of movement at the moment the storm begins. (See *A*, Fig. 1.) Accordingly, an observatory which registers the storm at six o'clock local time should be the first of all to record it; next would follow those nearer to it on either side, and last of all the one at which the storm began at 18^h local time.

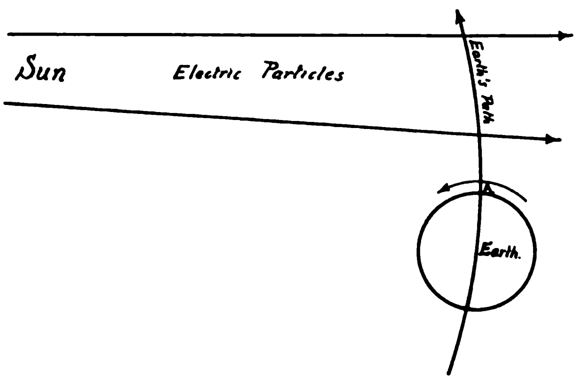

Fig. 1.

As it does not seem possible that a cloud at a distance of 150 million kilometers in free space has an effective transversal velocity greater than 2 kilometers per second, caused by the solar rotation by which it was projected, a rough approximation of the time required for the Earth to become involved in the cloud can be easily obtained from its orbital velocity; this amounts to about six and a half minutes, a little longer than that found experimentally by Bauer. It may be that when half, or even a greater part of the

TABLE 1.—*Greenwich times of beginnings of 15 magnetic storms, and differences as compared with times at Tortosa.**

Number	Station (S)	Latitude	Longitude	12 W. 1910 Oct. 12-14 18h		11 E. ah. 1910 Oct. 19 (8)7h		6 E. ah. 1911 Mar. 20 (5)0h		5 E. ah. 1914 Jul. 5-6 (6)1h		10 W. ah. 1914 Oct. 27 16h		12 W. ah. 1916 Aug. 22 (4)18h		11 E. ah. 1916 Aug. 25 (7)19h		11 E. ah. 1917 Aug. 25 (3)19h		0 ah. 1917 Sep. 5 (1)6h		12 W. ah. 1919 Jan. 3 (1)18h		11 E. ah. 1919 Feb. 27 19h		0 ah. 1919 May 21 6h		1 W. ah. 1919 Aug. 11 (1)6h		3 W. ah. 1920 Mar. 22 (1) 9h		7 W. ah. 1921 May 13 (1)13h		Mean (S-T)
				S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	
		° ′	° ′	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
1	Mel.	37 49 S	144 58 E	30	0							15	−3	30	+3.4			44	+2	5	−3	10	0	25	+1	30	+5	55	−3	8	−2	9	−1	−0.05
2	Anti.	14 36 N	121 10 E	33	+3							9	(−9)	20	(−6.6)			34	(−8)	23	(+15)	6	−4	20	−4	13	(−12)	55	−3	10	0	6	−4	−2.0
3	Luk	31 21 N	121 01 E									14	−4	25	−1.6			34	(−8)	10	+2	12	+2	25	+1	25	0	58	0					−0.08
4	Wath.	30 20 S	116 01 E																									55	−3	9	−1	9	−1	−1.7
5	Ali.	18 38 N	12 52 E																													11	+1	+1.0
6	**Tort.**	40 49 N	0 30 E	30	0	13		49		29.4		18	0	26.6	0	44		42	0	8	0	10	0	24	0	25	0	58	0	10	0	10	0	0.0
7	R'co	18 08 N	65 25 W									17	−1	30	+3.4			41	−1	9	+1	11	+1	27	+3	23	−2	58	0	10	0	9	−1	+0.3
8	Chel.	38 44 N	75 50 W											27	+0.4			41	−1	8	0	11	+1	26	+2	24	−1	57(9)	−1	10	0	10	0	+0.04
9	Tor.	43 39 N	79 23 W	27(a)	−3							21	+3	26	−0.6			30(c)	(−12)	8	0	10(b)	0	24	+0			57	−1	9	−1	10	0	−0.3
10	Tuc.	32 15 N	110 50 W											27	+0.4			41	−1	8	0	10	0	25	+1	24	−1	57	−1	10	0	10	0	−0.2
11	Sit.	57 03 N	135 20 W									21	+3	26	−0.6			41	−1	8	0	11	+1	26	+2	25	0	56	−2	10	0	10	0	+0.2
12	Hon.	21 19 N	158 03 W									15	−3	26	−0.6			41	−1	7	−1	10	0	24	0	24	−1	57	−1	10	0	10	0	−0.8
13	Apia	13 48 S	171 43 W																													9	−1	(−1)
Sum of residuals, S-Tortosa					0								−14		−2.4				−31		+14		+1		+6		−12		−15		−4		−7	
Sum, omitting figs. in parentheses													−5		+4.2				−3		−1		+1		+6		0		−15		−4		−7	
Mean deviation from Tort. time													−0.7		+0.5				−0.4		−0.1		+0.1		+0.6		0		−1.4		−0.4		−0.6	−0.30

(1) Very definite in *H*, *Z* and *D*. (3) The peak in *H* and *Z* at the beginning. (4) Very definite in *H* and *Z*; *D* 3 min. later. (5) Very definite in *H*. (6) Very definite in *H* and *Z*. (7) Very definite in *H*, *Z* and *D*. (8) Very definite in *H*. (9) This value was communicated by letter; the value given in *Terr. Mag.*, Sept., 1919, by Geo. Hartnell is 58m. a. Indefinite beginning value for *H*. b. In *H*. c. Uncertain.

*In the first row of this table is given for each storm the position of the "front meridian," as defined by the author in the text; *ah.* stands for "ahead."—*Ed.*

TABLE 2.—*Times of sudden beginnings of magetic storms, 1906-09.*

Date	Mag. El.	Porto Rico		Chel-tenham		Bald-win		Sitka		Hono-lulu		Merid-ian ahead	Time-Differences (n-1)				Sum	
		m	n	m	n	m	n	m	n	m	n		m	m	m	m	m	m
1906 Jul. 29	D	....		56.0	(4)	54.4	(3)	55.4	(2)	54.9	(1)	11 E	+0.5	−0.5	+1.1	.....	+1.1	
19^h	H	58.1	(5)	57.8		54.4		55.4		54.9			+0.5	−0.5	+2.9	+3.2	+6.1	
	Z	....		58.1		55.6		58.4		54.0			+4.4	+1.6	+4.1	.....	+10.1	
Aug. 7	D	....		39.3	(2)	39.3	(1)	38.6	(3)	39.9	(5)	7W	0.0	.....	−0.7	+0.6		−0.1
13^h	H	37.2	(2)	39.9		38.7		37.1		37.8			+1.2	−1.5	−1.6	−0.9		−2.8
	Z	....		....		42.3		38.6		39.0			.....	.....	−3.7	−3.3		−7.0
Dec. 21	D	34.5	(5)	31.1	(4)	33.1	(3)	29.3	(1)	30.3	(1)	9 E	.....	+3.3	+1.3	+4.7	+9.3	
21^h	H	34.5		32.0		32.5		26.9		27.3			.....	+5.4	+4.9	+7.4	+17.7	
	Z	33.9		35.3		35.5		30.2		29.1			.....	+5.9	+5.7	+4.3	+15.9	
1907 Feb. 9	D	14.3	(3)	14.0	(2)	15.2	(1)	12.3	(2)	10.4	(1)	8W	−0.5	+1.2	+1.5	.....	+2.2	
14^h	H	12.8		13.4		14.3		11.4		11.9			−1.7	+0.3	−0.3	.....		−1.7
	Z	14.6		16.4		18.2		12.9		16.4			−4.4	−0.9	−2.7	.....		−8.0
Jul. 10	D	24.4	(3)	23.6	(2)	24.4	(1)	22.5	(2)	21.8	(1)	8W	−0.6	+0.5	+1.3	.....	+1.2	
14^h	H	24.7		24.2		22.6		22.2		20.9			+0.5	+2.5	+3.0	.....	+6.0	
	Z	25.6		25.4		25.0		24.6		25.8			−0.8	0.0	+0.2	.....		−0.6
Oct. 13	D	45.4	(1)	42.3	(2)	41.8	(3)	40.2	(4)	41.8	(5)	2W	−3.1	−3.6	−5.2	−3.6		−15.5
7^h	H	42.4		44.1		43.6		40.2		41.5			+0.7	+1.2	−2.2	−0.9		−0.2
	Z	44.5		47.7		....		42.6		45.7			+3.2	.....	−1.9	+1.2	+2.5	
1908 Mar. 26	D	40.5	(4)	42.6	(4)	....	(3)	....	(2)	42.4	(1)	11W	.....	.....	+0.2	−1.9		−1.7
17^h	H	39.4		40.2		42.0		....		42.3			.....	−0.3	−2.1	−2.9		−5.3
	Z	43.8		44.1		45.8		....		45.9			.....	−0.1	−1.8	−2.1		−4.0
Aug. 19	D	10.0	(4)	15.0	(3)	14.0	(2)	14.9	(1)	14.7	(1)	6 E	−0.8	+0.2	−4.8	.....		−5.4
0^h	H	14.2		14.4		14.0		14.6		14.7			−0.6	−0.2	−0.4	.....		−1.2
	Z	16.0		....		....		16.4		18.7			.....	.....	−1.5	.....		−1.5
Sept. 11	D	21.7	(1)	21.0	(2)	20.3	(2)	22.2	(3)	22.1	(5)	1W	−0.7	−1.4	+0.5	+0.4		−1.2
7^h	H	20.8		20.9		20.7		20.2		21.5			+0.1	−0.1	−0.6	+0.7	+0.1	
	Z	23.2		23.1		23.7		22.9		24.5			−0.1	+0.5	−0.3	+1.3	+1.4	
Sept. 11	D	49.2	(5)	46.4	(4)	44.5	(3)	47.8	(2)	45.4	(1)	9W	+2.4	−0.9	+1.0	+3.8	+6.3	
21^h	H	48.0		46.7		48.1		47.5		46.9			+0.6	+1.2	−0.2	+1.1	+2.7	
	Z	50.7		49.1		49.6		48.7		48.1			+0.6	+1.5	+1.0	+2.6	+5.7	
Sept. 28	D	42.7	(1)	43.0	(2)	41.5	(2)	42.5	(3)	42.1	(3)	3W	+0.3	−1.2	−0.2	−0.6		−1.7
8^h	H	41.5		43.6		41.2		41.3		42.4			+2.1	−0.3	−0.2	+0.9	+2.5	
	Z	44.2		46.0		....		45.5		42.9			+1.8	.....	+1.3	−1.3	+1.8	
Sept. 29	D	34.0	(5)	34.3	(3)	31.4	(2)	....	(1)	30.9	(1)	5W	+0.5	+3.4	.....	+3.1	+7.0	
1^h	H	31.9		33.4		31.4		....		30.0			+1.4	+3.4	.....	+1.9	+6.7	
	Z	34.3		34.3		33.2		....		31.5			+1.7	+2.8	.....	+2.8	+7.3	
1909 May 14	D	56.4	(1)	57.2	(1)	57.7	(2)	58.0	(3)	54.0	(5)	1 E	+0.9	+1.2	.....	−2.8		−0.7
4^h	H	54.3		57.2		56.8		53.7		53.1			+1.1	−2.0	.....	−2.6		−3.5
	Z	58.4		58.3		60.7		60.7		56.4			+2.3	+2.3	.....	−2.0	+2.6	
Sept. 25	D	39.8	(1)	41.5	(2)	39.3	(2)	40.3	(3)	42.7	(5)	3W	+1.7	−0.5	+0.5	+2.9	+4.6	
8^h	H	37.7		40.9		38.7		39.5		42.7			+3.2	+1.0	+1.8	+5.0	+11.0	
	Z	38.6		....		42.3		42.2		....			+3.7	+3.6	.....	.....	+7.3	
Sept. 25	D	39.8	(1)	42.1	(2)	40.8	(2)	42.2	(3)	46.3	(5)	6W	+2.3	+1.0	+2.4	+6.5	+12.2	
11^h	H	39.8		43.3		41.1		39.8		45.4			+3.5	+1.3	0.0	+5.6	+10.4	
	Z	41.0		45.1		41.1		....		49.0			+4.1	+0.1	.....	+8.0	+12.2	
												Sums	+33.0	+31.4	+4.3	+43.1	+173.9	−62.1

Earth, is immersed in the electric cloud, induction phenomena are produced which advance the time of beginning at the other stations.

The writer has tried to ascertain whether this explanation is supported by facts and for this purpose has rearranged the data collected by R. L. Faris as given in Table 2.[3] To each station is assigned a number indicating the order of succession for the registration of each storm, according to the "front meridian" given in the eighth column; when the distance of two stations from the "front meridian" was practically equal, the same number has been given and the mean of their distances is used. In the ninth column are given the differences, second station minus first, third minus first, etc. Now, according to the hypothesis under consideration, these differences should be positive, and the results of Table 2 seem to favor this conclusion since the sum of all the differences is positive in each case, and the general positive mean is about three times greater than the negative one.

In order to obtain more definite results I have taken only the two stations, Cheltenham and Honolulu, which are separated by about 82 degrees of longitude; the first column of Table 3 gives the "front meridian" at the time of beginning and the stations are

TABLE 3.—*Comparison of recorded times of magnetic storms, 1906-1909, at Honolulu and Cheltenham.*

Front Merid.	Date	Hour	Honolulu	Cheltenham	b−a, or a′−a	
		h	m	m	m	m
XI E	1906, Jul. 29	19	54.6 a	57.3 b	+ 2.7	
VII W	Aug. 7	13	38.9 a	40.3* a′	+ 1.4	
IX E	Dec. 21	21	28.9 a	32.8 b	+ 3.9	
VIII W	1907, Feb. 9	14	12.9 a	14.6 a′	+ 1.7	
VIII W	Jul. 10	14	22.8 a	24.4 a′	+ 1.6	
II W	Oct. 13	7	43.0 b	44.7 a		− 1.7
XI W	1908, Mar. 26	17	43.5 a	42.3 b		− 1.2
VI E	Aug. 19	0	16.0 a	15.4* a′		− 0.6
I W	Sept. 11	7	22.7 b	21.7 a	+ 1.0	
VIII E	Sept. 11	21	46.8 a	47.4 b	+ 0.6	
III W	Sept. 28	8	42.5 b	44.2 a		− 1.7
V E	Sept. 29	1	30.8 a	34.0 b	+ 3.2	
II E	1909, May 14	4	54.5 a′	57.6 a		− 3.1
II W	Sept. 25	8	43.4* b	41.9* a	+ 1.5	
V W	Sept. 25	11	46.9 b	43.5 a	+ 3.4	
				Sum...	+21.0	− 8.3

*In deriving these quantities, the author appears to have used some method for supplying missing data in Table 2.—*Ed.*

[3]See GIUSEPPE GIANFRANCESCHI, S. J., "Velocità istantanea della Terra," Roma, *Mem. Acc. Nuove Lincei*, Ser. 2, vol. 4.

marked a or b (a, a', if the difference is negligible), according to their distance from it. Here again the sum of the positive differences b-a is nearly three times as large in absolute value as the sum of a-b.

There are still some very conspicuous exceptions to the rule given, but the agreement is close enough to justify further investigation of the subject.

It is also possible that some of the electric clouds are of cosmic character and have their own velocities. The movement of the whole planetary system, through space and the angle which the direction of the instantaneous apex[4] makes with the Sun-Earth line, might affect the results for such cases. It would be very desirable, were it possible, to compare the beginning of magnetic storms on different planets, but as there is no hope, for the present at least, of obtaining records of such storms, experienced on Jupiter or on Saturn, for example, we must confine our investigations to our own Earth, collecting as many carefully-recorded data as possible.

Observatorio del Ebro,
Tortosa, Spain.

[4]See footnote 1.

LETTERS TO EDITOR

PROVISIONAL SUN-SPOT NUMBERS FOR JULY TO SEPTEMBER, 1922.[1]

Day	July	Aug.	Sept.	Day	July	Aug.	Sept.
1	0	0	6	18	0	0	7
2	0	0	..	19	..	0	8
3	0	7	0				
4	0	7	0	20	28	0	7
5	15	7	0	21	22	0	8
6	24	15	0	22	28	0	7
7	19	8	6	23	..	..	8
8	29	0	..	24	19	17	7
9	..	0	..	25	20	..	0
				26	13	..	0
10	16	0	..	27	7	23	7
11	7	0	0	28	7	16	7
12	7	0	..	29	0	19	..
13	0	0	8				
14	0	0	12	30	0	14	8
15	..	0	..	31	0	15	
16	0	0	7				
17	0	0	7	Means	9.7	5.3	5.2

A. Wolfer.

[1]For previous table, see *Terr. Mag.*, **27**, 120, 1922.

EARTHQUAKE RECORDS, WATHEROO MAGNETOGRAMS, NOVEMBER, 1921.

There was a record of an earthquake on the magnetograms of the Watheroo Magnetic Observatory, Western Australia, on November 11, 1921. The declination and horizontal-intensity traces showed a slight broadening, while there was a very slight blurring of the vertical-intensity trace. The extreme Greenwich mean times of the record were from $18^h\ 45^m$ to $19^h\ 01^m$ for declination, $18^h\ 44^m$ to $18^h\ 56^m$ for horizontal intensity, and $18^h\ 52^m$ to $18^h\ 59^m$ (uncertain) for vertical intensity. Mr. Curlewis, Government Astronomer at Perth, reported the following times of phases as obtained on the seismograph: $18^h\ 43^m\ 56^s.6$, *P;* $18^h\ 46^m\ 00^s.5$, uncertain; $18^h\ 50^m\ 10^s.4$, *L.*

G. R. Wait, *observer-in-charge.*

EARTHQUAKE RECORDS, HUANCAYO MAGNETOGRAMS, OCTOBER-NOVEMBER, 1922

The details of the records, as measured on the magnetograms of the Huancayo Magnetic Observatory, Peru, are as follows, the times indicated being Greenwich civil mean time:

1. *October 11, 1922.*

Magnetic Element	Beginning		End		Maximum amplitude
	h	m	h	m	mm.
Declination	14	51	14	55	2.0
Horizontal intensity	14	52	14	56	2.5
Vertical intensity	14	52	14	56	2.5

This earthquake was recorded also on the seismograph of the Harvard College Observatory, at Arequipa, Peru. Some damage was done to property in the neighborhood of Arequipa, and a few persons were injured.

2. *Great Chilean Earthquake.*

The Chilean earthquake effect was recorded at Huancayo only on the vertical-intensity magnetogram, the effect beginning at G. M. T. $4^h\ 35^m$ and ending at $5^h\ 15^m$, November 11, 1922; the maximum amplitude of the effect was about 1.0 mm. at $4^h\ 45^m$.

W. F. WALLIS, *observer-in-charge.*

COMMENTS ON WEINBERG'S SUGGESTIONS FOR FIELD WORK.

Concluded from page 156.

and it has frequently happened that determinations of the three elements have been made within an hour's time. In every case, however, when partial observations are made because of scant time available, the constancy of the magnetic moment for the magnetometer-magnet and of the relative constants involved in the total-intensity observations are controlled by complete sets of observations at preceding and succeeding stations.

As regards the matter of timing of oscillations, the half-second pocket chronometer has been found sufficiently reliable in our field practice. Several attempts have been made to use stop watches for such work, but without very satisfactory results. The suggestion that the determination of plane of detorsion be omitted is subject to criticism since such procedure would introduce a great element of uncertainty in the determination as, for example, the accidental accumulation of 180° or 360° of torsion through rotation of the suspension stirrup. It seems inadvisable also to use shorter or coarser suspensions for magnetometers in declination work since it has been found in actual experience that observers may use for periods of from one to two years in the field the same light-weight fiber with a torsion effect which is small.

INVESTIGATION OF LOCAL MAGNETIC DISTURBANCES AT PORT SNETTISHAM, ALASKA.

By N. H. Heck.

The United States Coast and Geodetic Survey is now carrying on its work in Alaska primarily by large parties, each using a vessel and several large launches to carry on all the operations necessary to a complete survey. The magnetic work included is at present confined to compass-declinometer observations on shore and to declination observations aboard ship made chiefly in areas of local disturbances.

The adoption of steel vessels on the one hand and the vastly more satisfactory observations obtained on a non-magnetic vessel such as the *Carnegie*, however, have made the continuance of observations on the Coast and Geodetic Survey vessels of doubtful desirability, except in special cases.

Areas of local disturbances may be known from previous surveys, or as the result of obtaining compass-declinometer observations at triangulation stations along the shores at an average distance of about two miles.

The area of Port Snettisham, Alaska, was known to be highly disturbed, but no detailed facts were available. Recent commercial developments, which required large vessels to enter this port, made a magnetic survey of considerable importance. The diagram (Fig. 1) brings out the results of the survey, though it fails to show that observations were made at 34 shore stations and 111 sea stations by the party on the United States Coast Survey Steamer *Explorer*. The depth of water is shown in feet. Reference to the scale of statute miles indicates the considerable extent of this area. The curves shown represent the departure of the declination from the normal values, the plus sign indicating easterly and the minus sign westerly departures.

Unfortunately, owing to the lack of time and the dense forest, it was impossible to investigate the existence of a local magnetic pole. The outstanding feature in this case is the extension of great local disturbance into areas of great depths. It will be noted that the 20° curve extends ¾ of a mile from the shore into a maximum depth of 772 feet.

The methods used in making the survey are of particular interest; the standard practice of the Coast and Geodetic Survey in hydrographic work was followed. Plane table triangulation was extended from the entrance of Port Snettisham to the shore indicated on the eastern side of the diagram and also into the south arm. Stations were temporarily marked by small signals and white-wash on the rocks; intermediate points were marked by white-wash or small flags, but no signals were built, in order to avoid confusion.

Each shore station was occupied with compass declinometer, the true azimuth of some other station being obtained from the results of the plane table triangulation. It was found necessary, owing to the rapid change in the dip, to shift the balancing weight on the south arm of the compass needle at nearly every station.

The methods used aboard ship were adapted to getting rapid observations. A system of lines was run just as in hydrography, the vessel proceeding at a speed of about six miles an hour. As the compass could not be used for keeping the vessel to its path, the method of steering for a point ahead on the land was adopted. Three-point fixes were taken at two or three-minute intervals, according to conditions. These were followed immediately by taking the compass bearing of one of the shore stations, preferably one nearly ahead or astern. The ship's head by compass was noted at the same instant. As the observers were skilled, the whole observations were practically simultaneous; the three-point fixes were plotted to direct the course of the vessel, but no effort was made to measure the azimuth until later.

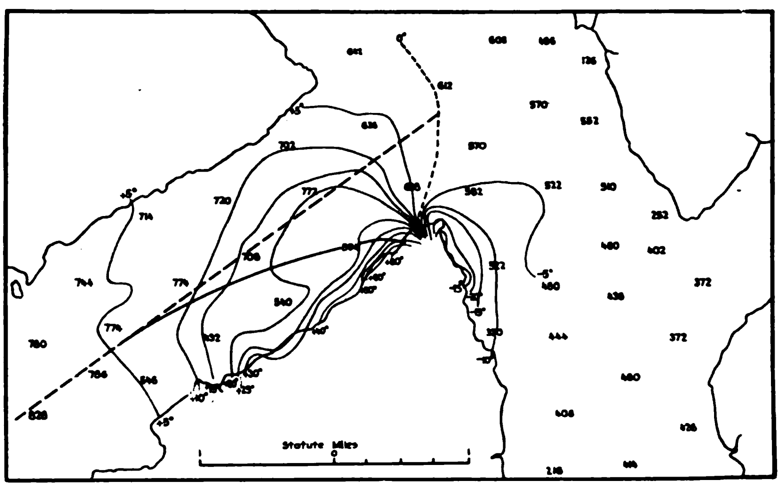

FIG. 1.—AREA OF MARKED LOCAL DISTURBANCE AT PORT SNETTISHAM, ALASKA, ABOUT 50 MILES SOUTH OF JUNEAU.

(The heavy broken line is path of vessel following mid-channel compass course, if there were no local disturbance. The heavy line is path taken by the same vessel steering in the same compass course as on entering.)

The compass deviations were obtained from swings in an undisturbed region; they were comparatively small, but were used to correct all compass bearings. All crossings check within half a degree, even where the amount of disturbance was considerable. The behavior of the compass on a close inshore line parallelling the south shore is of great interest. In proceeding from the entrance

to Port Snettisham, the compass was first affected at a distance of about three miles from Sentinel Point; it gradually swung to the eastward of magnetic north until it pointed 41° east of magnetic north, it then suddenly spun around to a position 15° west of magnetic north, and then gradually came back to normal.

This is by no means the first investigation of such an area. Another notable instance is that at Douglas Island, near Juneau, where Dr. L. A. Bauer in 1907 found a local magnetic pole. The investigations of H. M. S. *Penguin*[1] were of a similar character, though the disturbed area was entirely submerged and the area was less. An investigation of a similar character to that described has been recently made in Chilkat and Chilkoot Inlets, Lynn Canal, Alaska, but the results are not yet available.

The geological character of a region of such marked magnetic disturbance, as the one at Port Snettisham, is of great interest, especially since the area involved is by no means small. It is estimated that the disturbance is strong over an area of eight square miles of land and water, and is felt over an area of 20 square miles. Rocks along the shore indicate the presence of considerable magnetite. In view of the fact that the local magnetic pole on Douglas Island is not far from the well-known Treadwell gold mine, it may be of some interest to point out that there are also gold mines in the vicinity of Port Snettisham. An extended investigation would probably be necessary to determine the exact manner in which the iron appears and whether there are deposits of commercial value.

U. S. Coast and Geodetic Survey,
Division of Terrestrial Magnetism.

[1]London, *Phil. Trans. R. Soc.*, A, v. 187, 1896 (345-381).

NOTES

22. *Principal Magnetic Storms at Cheltenham Magnetic Observatory, July to December, 1922.*[1]

[1]Communicated by E. Lester Jones, director, U. S. Coast and Geodetic Survey: Geo. Hartnell, observer-in-charge; Lat. 38° 44'.0 N; Long. 76° 50'.5, or 5 h 07.m4 west of Greenwich.

Greenwich Mean Time		Range		
Beginning	Ending	Decl'n	Hor'l Int.	Vert'l Int.
h m	h m	'	γ	γ
Sept. 13, 3 24	Sept. 15, 5 ..	30.4	179	232
Oct. 5, 2 ..	Oct. 7, 3 ..	32.5	193	92

23. *Erratum, General Report of Rome Meeting, International Section of Terrestrial Magnetism and Electricity.*—In the French translation of Resolution 4, as given on p. 99 of *Terr. Mag.*, vol. 27, or on p. 11 of "Bulletin No. 2," 9 important concluding words were omitted. The resolution should read:

4. Que les Comités Nationaux soient priés de désigner, s'il est possible, un

observatoire central pour leurs pays respectifs, chargé des comparaisons internationales des instruments magnétiques, et d' assurer dans leurs propres pays une comparaison des instruments magnétiques au moins une fois tous les trois ans.

24. *Second Pan-Pacific Scientific Congress and the Australian National Research Council.*—The Australian National Research Council has fixed the date of the Second Pan-Pacific Scientific Congress as August 13 to September 3, 1923. The first session is to be held at the University of Melbourne, and the second session (August 21 to September 3), at the University of Sydney. Excursions are planned as part of the congress program and, after adjournment of the formal meeting, there will be opportunities for visits to other parts of the continent. The Australian Federal Government has made a liberal grant for meeting the necessary expenses. We regret to learn that, owing to a severe illness arising from a wound received during the war in France, *Sir T. W. Edgeworth David* has resigned his position as president of the Australian National Research Council. His place, however, has been ably filled by the election of *Dr. Orme Masson*, professor of chemistry in the University of Melbourne. Professor David continues to serve the council as vice-president.

25. *Amundsen Arctic Expedition, 1922.*—According to information received from the Chief of the United States Weather Bureau, Professor C. F. Marvin, wireless reports of meteorological observations made aboard the *Maud* came intermittently until August 17, then nothing was received until September 28, 1922, when ten reports came in; nothing has been received since then. The geographic position of the *Maud* when the last report was received (September 28) was: Latitude, 73°N., longitude, 176°W., hence, about 100 miles north of Wrangell Island. According to newspaper reports, Captain Amundsen arrived on December 14, by dog-team, at Nome, Alaska, from Wainwright, near Point Barrow, where he is wintering. [As the Journal is passing through the press, a wireless message of December 15 has been received *via* the radio station at Spitsbergen from Capt. Wisting, aboard the *Maud*, in lat. 73° 20′ N., long. 173° W. (? E.).]

26. *Personalia.* — Prof. *G. Hellmann* has retired from the post of director of the Prussian Meteorological Institute, which he had filled so successfully since von Bezold's death. Dr. *E. Marsden* has resigned his professorship of physics in the Victoria University College at Wellington, in order to accept the post of Assistant Director of Education in the New Zealand government service. Dr. *Robert A. Millikan* has been appointed a member of the Committee on Intellectual Cooperation of the League of Nations to succeed Dr. George E. Hale, who has resigned from the committee. A royal medal has been awarded by the Royal Society of London to *C. T. R. Wilson* for his researches on the condensation nuclei and atmospheric electricity. The Paris Academy of Sciences awarded the Janssen medal to *Carl Störmer* for his investigations of the aurora. We regret to record the death, on September 27, of Prof. *C. Michie Smith*, government astronomer of Madras, 1891-1911, and director of the Kodaikanal and Madras Observatories, 1899-1911.

LIST OF RECENT PUBLICATIONS

A. *Terrestrial and Cosmical Magnetism.*

AGINCOURT AND MEANOOK OBSERVATORIES. Results of observations at the Canadian magnetical observatories, Agincourt and Meanook, The year 1919. Prepared by W. E. W. Jackson, under the supervision of Sir Frederic Stupart, Director of the Meteorological Service of Canada. Ottawa, F. A. Ackland, 1922 (40 with 13 pages of magnetograms).

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TERRESTRIAL MAGNETISM
AND
ATMOSPHERIC ELECTRICITY

AN INTERNATIONAL QUARTERLY JOURNAL

Conducted by
LOUIS A. BAUER
Department Terrestrial Magnetism, Carnegie Institution of Washington, D. C.

VOLUME XXVIII
MARCH—DECEMBER, 1923

THE JOHNS HOPKINS PRESS
BALTIMORE, MARYLAND
1923

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PUBLISHED FOR

THE JOHNS HOPKINS PRESS, BALTIMORE

THE ABINGDON PRESS, 420 PLUM ST., CINCINNATI, O.

THREE DOLLARS AND FIFTY CENTS A YEAR SINGLE NUMBERS, ONE DOLLAR

THIS DOUBLE NUMBER, TWO DOLLARS

WHELDON & WESLEY, Ltd., 28 Essex St., Strand, LONDON, W. C., 2

THE ABINGDON PRESS (Cash Subscription) 420 Plum St., CINCINNATI

MAYER & MÜLLER Prinz Louis-Ferdinand St. BERLIN

Entered as second-class matter at the Post-office at Cincinnati

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I hold every man a debtor to his profession; from the which as men of course do seek to receive countenance and profit, so ought they of duty to endeavour themselves by way of amends to be a help and ornament thereunto.—*Francis Bacon.*

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Washington, D. C., May 1, 1923. JOURNAL OF TERRESTRIAL MAGNETISM AND ATMOSPHERIC ELECTRICITY.

NOTICE

Nos. 2 and 4 of Vol. I (April and October, 1896), and No. 1 of Vol. III (March, 1898), of the Journal *Terrestrial Magnetism and Atmospheric Electricity*, in response to numerous demands, have been reprinted. A few complete sets can still be supplied.

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Terrestrial Magnetism
and
Atmospheric Electricity

VOLUME XXVIII | MARCH-JUNE, 1923 | NOS. 1 AND 2

CHIEF RESULTS OF A PRELIMINARY ANALYSIS OF THE EARTH'S MAGNETIC FIELD FOR 1922—No. 1.

BY LOUIS A. BAUER.

Abstract.—From a new analysis of the Earth's magnetic field for 1922, made as free as possible without assumptions as to the composing systems and restricted to the region of the Earth (86 per cent), from 60°N to 60°S, the author concludes that for a satisfactory representation of the observed data it is necessary to recognize the existence of an internal magnetic system, I, an external system, E, and a non-potential system, N, or of three equivalent systems, X, Y, Z. The system I constitutes about 94 per cent of the total field, and E and N each about half of the balance of 6 per cent.

He shows that the magnetic secular variation system is as complex as the Earth's total magnetic field existing at any one time, and that in addition to changes in the direction of magnetization with the lapse of time there is also a change in the average equivalent intensity of magnetization. The latter quantity has been steadily diminishing during the past 80 years at the average annual rate of about 1/1,500 part.

For further statement of results, reference may be made to the "Summary of Chief Conclusions" at the close of the paper.

ZONAL HARMONICS AND UNIFORM MAGNETIC FIELD.

INTRODUCTION.

1. A new analysis of the Earth's magnetic field has been in course of preparation since 1912, but various interruptions, caused chiefly by the World War and the desire to obtain additional magnetic data for checking results already obtained in 1912 and before, have led to postponement of publication. The main purpose was to obtain the necessary facts for preliminary studies and discussions of the outstanding, greater problems of the Earth's magnetic and electric phenomena, and help to decide in what localities of the Earth it was desirable to intensify the field work in progress, and what additional allied scientific data should be included in the observational program. The studies thus far have indicated that there are such intimate relationships between the phenomena of terrestrial magnetism, earth currents, polar lights, atmospheric

electricity, and solar activity as to make combined treatment at times highly advantageous; several papers of this character have already been published by the author.

2. Naturally, as progress was made, and additional investigational data became available, some of the conclusions previously reached in two series of papers[1] have been in part superseded and in part modified by the results of the later investigations. In the main, however, the chief conclusions have been confirmed by the results in this paper, as will be indicated elsewhere.

The opinion, which I have several times expressed, that it was doubtful whether we should ever be able to solve the problem as to the origin of terrestrial magnetism until we had found out what causes the Earth's magnetism to vary, has been strengthened by the subsequent studies. It would also seem safe to conclude that the problem of the origin and maintenance of the Earth's electric charge will find its surest approach to a solution by means of the striking variations, geographical, daily, annual, sun-spot, etc., to which atmospheric-electric phenomena are subject.

3. To satisfy practical demands, the Department of Terrestrial Magnetism has always made a special endeavor to supply promptly its latest magnetic data to the leading hydrographic establishments and other interested organizations. Our ocean data, for example, not infrequently have been at the disposal of establishments issuing magnetic charts, within three or four months after the observational work has actually been done. For the most recent world magnetic charts, those for 1922, by the British Admiralty, there were made available to the Greenwich Observatory, which has charge of the construction of these charts, the results of the cruises of the "Carnegie" through November, 1921. These charts may be regarded probably as a close approximation to the world magnetic charts, which the Department of Terrestrial Magnetism itself has in preparation and in which an attempt at complete and accurate reduction of the observed magnetic data will be made. During 1922 and 1923 the Department of Terrestrial Magnetism has reoccupied a large number of its stations, established in previous years in all parts of the Earth. Thus we now possess more complete knowledge of secular magnetic changes than was available to the Greenwich Observatory for the 1922 charts.

However, the 1922 magnetic charts of the British Admiralty and

[1] Physical Decomposition of the Earth's Magnetic Field, *Terr. Mag.*, 1899-1904, and Physical Theory of the Earth's Magnetic and Electric Phenomena, *Terr. Mag.*, 1910-1912.

the 1920 magnetic charts of the United States Hydrographic Office may be regarded as the most correct charts heretofore available for an analysis of the Earth's magnetic field. Hence, in continuation of our preparatory studies, it was thought highly desirable to undertake a preliminary analysis, with all possible requisite rigor, using the magnetic data, chiefly for 1922, derived from these charts, with such corrections applied as were indicated by more recent observations. The immediate stimulus to bring to preliminary conclusion, at least, a new analysis of the Earth's magnetic field was the preparation of a lecture entitled "The Greater Problems of the Earth's Magnetism and their Bearings on Astronomy, Geology, and Physics," delivered at the Carnegie Institution of Washington on November 21, 1922. In that lecture the chief facts disclosed by the new analysis were announced, as also some later results at the Boston meetings, last December, of the American Physical Society and the American Astronomical Society. (See abstracts, *Physical Review*, March, 1923, pp. 370-371 and 388; also *Popular Astronomy*, March 1923, p. 186.)

4. The analysis has been made as free as possible from assumptions regarding the actual constitution of the Earth's magnetic field, and has been restricted, for the present, to the region between parallels 60°N and 60°S, which embraces 86 per cent of the Earth's total surface. Before the polar caps may be safely included in the analysis it will be necessary to examine carefully the available magnetic data for these regions and even, possibly, await additional data. *There is evidence that the Gaussian coefficients, defining the Earth's magnetic field, are to be regarded at first as purely empirical quantities and, hence, strictly applicable only to the region of the Earth from which they were derived.* It is believed, however, that the subsequent inclusion of the polar caps will not materially alter the main conclusions drawn in this paper.

The spherical harmonic expansion was carried to the sixth harmonic, and, in some cases, to the seventh; a separate series for each of the three rectangular components, X (positive towards geographic north), Y (positive towards geographic east), and Z (positive towards nadir), was established, and the Earth was treated as a spheroid of revolution. In order to get results strictly comparable with those obtained by Adolf Schmidt for 1885, whose analysis also applied to the region 60°N to 60°S, his general method of mathematical analysis was adopted for our preliminary computations, though some modifications have suggested themselves,

which may be advantageously incorporated in the final analysis. Further details will be reserved for the more extended publication. The magnetic data utilized apply in general to longitude intervals of 10° and latitude intervals of 5°. *Before passing to the results, which, in the nature of the case, are to be regarded as preliminary and subject to minor modifications when the final analysis has been completed,* acknowledgement should be made of the very effective and devoted assistance received in the computational work from Messrs. W. J. Peters, C. R. Duvall, C. C. Ennis, and Miss Emma L. Tibbetts, all of the staff of the Department of Terrestrial Magnetism.

EARTH'S MAGNETIC FIELD SYMMETRICAL ABOUT AXIS OF ROTATION.

5. Let us consider first only that portion of the Earth's magnetic field, symmetrical about the axis of rotation of the Earth, in brief, that portion which may be represented by zonal harmonics. Throughout this paper the coefficients, g, h, will be regarded as applying to Gauss's "P" functions, and the coefficients γ, η, to Schmidt's "R" functions, and, in general, the same notation will be followed as in previous papers.[1]

Table 1 contains the zonal coefficients corresponding to the six harmonics used in the expansion and for four epochs, 1842-1922, all computed anew, taking the Earth as a spheroid of revolution, except the 1885 quantities which were derived from Schmidt's calculations. If X_a and Z_a represent, respectively, the average values of the X's and Z's, at equidistant intervals of longitude along a parallel of latitude, then two harmonic series were separately established to represent, respectively, the variations of X_a and of Z_a from parallel to parallel for the region 60°N to 60°S. Next the separation into an internal field (I) and external field (E) was made according to the usual process.

If u is the co-latitude and the Earth be regarded as uniformly magnetized parallel to the axis of rotation, and if the exponents, i and e, refer to the internal and external fields, respectively, and the Earth be considered a sphere, then the following simple formulæ, would obtain:

$$X_a^i = -\sqrt{3}.\gamma_{10}^i \sin u;\ X_a^e = -\sqrt{3}.\gamma_{10}^e \sin u;\ X_a = X_a^i + X_a^e; \tag{1}$$

$$Z_a^i = -2\sqrt{3}.\gamma_{10}^i \cos u;\ Z_a^e = +\sqrt{3}.\gamma_{10}^e \cos u;\ Z_a = Z_a^i + Z_a^e, \tag{2}$$

The coefficients, γ_{30} and γ_{50}, express the lack of strict uniformity of the portion of the magnetic field here considered, about the axis of

[1]See, for example, *Terr. Mag.*, vol. 8 (1903), 97-105.

rotation, whereas, the coefficients γ_{20}, γ_{40}, γ_{60} represent the lack of uniformity of this field about the equator.

TABLE 1.—*Coefficients of zonal portion of Earth's internal and external magnetic systems, 1842-1922, derived from magnetic data for 60°N to 60°S, in units of the fourth decimal C. G. S.*

Coeff.	1842		1880		1885		1922	
	I	E	I	E	I	E	I	E
$-\gamma_{10}$	+1863.0	+6.3	+1839.9	+0.1	+1832.1	+10.7	+1759.1	+30.2
$-\gamma_{20}$	− 3.0	+1.4	+ 25.5	−3.2	+ 23.4	− 0.1	+ 32.9	+ 7.9
$-\gamma_{30}$	− 31.4	−2.7	− 36.3	0.0	− 35.4	0.0	− 39.3	+ 3.2
$-\gamma_{40}$	− 23.4	+2.3	− 24.6	−4.3	− 26.5	− 1.2	− 32.4	+ 4.7
$-\gamma_{50}$	+ 0.5	+1.9	+ 4.8	−0.7	+ 5.1	+ 0.2	+ 6.6	+ 0.9
$-\gamma_{60}$	− 1.0	+0.2	− 0.1	−0.6	− 0.6	0.0	− 3.1	+ 1.4

6. *Main conclusions from Table 1.* It will be seen that:

a. For the internal system (I) there has been a steady decrease, between 1842 to 1922, in the principal coefficient, $-\gamma_{10}$, which is proportional to the component of magnetization parallel to the Earth's axis of rotation.

b. The largest value of the chief coefficient, $-\gamma_{10}$, for the external system (E) is that for 1922. Whether that is because of the greater extent and accuracy of the magnetic data for 1922, or whether the large changes, shown in the value of that coefficient from epoch to epoch, represent secular changes, or sun-spot cycle changes, cannot be definitely determined at present; it may chiefly be the result of the greatly improved ocean data. It is of significance, however, that, in general, the principal component of the external magnetic system, as shown by the quantity ($-\gamma_{10}$), is directed in the same manner, i. e., towards the North Pole, as is the corresponding component of the internal field.

c. It is also of significance that for the I-system the values of the two coefficients, ($-\gamma_{10}$) and ($-\gamma_{30}$), are shown to be of opposite sign for each epoch. This implies that if we take the portion of the Earth's magnetic field, symmetrical both about the axis of rotation and the equator, the average intensity of magnetization increases systematically towards the equator (*Cf. Terr. Mag.*, vol. 17, 1912, 140.)

7. To obtain a direct control on the steady decrease in the chief component of magnetization, which is revealed in Table 1, and would be reflected in the values of X_a and Z_a, Table 2 was prepared. The average annual changes, dX_a and dZ_a, are the numerical increases, or decreases, in the components, X_a and Z_a.

TABLE 2.—*Average annual changes in X_a and Z_a, 1842-1922, expressed in units › the fourth decimal C. G. S.*

Region	Average annual change					
	1842-1882		1862-1922		1882-1922	
	dX_a	dZ_a	dX_a	dZ_a	dX_a	dZ_a
60° N to 10° N	+0.6	−1.4	−0.3	−2.7	−0.7	−3.3
10° S to 60° S	−2.7	−0.7	−3.0	−3.3	−3.1	−4.6
60° N to 60° S	−1.0	−0.8	−1.6	−2.6	−1.8	−3.6

From Table 2 it will be observed that, on the average for the region 60°N to 60°S, the rectangular components X_a and Z_a have numerically diminished during the eighty-year period, 1842-1922, and that *the average annual decreases, in general, have been larger for the south, or water hemisphere, than for the north, or land hemisphere.* The average annual decreases, dX_a and dZ_a, for the entire region 60°N to 60°S, are largest for the 40-year period, 1882-1922; thus $dX_a = -0.00018$ C. G. S., or about 0.075 per cent of the average X_a, and $dZ_a = -0.00036$ C. G. S., or about 0.12 per cent of the average Z_a.

8. The effect of the distribution of land and water on the magnetic secular change, as apparently disclosed by Table 2, is one of extreme theoretical interest. In order to exhibit still more strikingly the possible effect of the distribution of land and water, the curves in Fig. 1 have been drawn for the two epochs 1885 and 1922. The radius vector from the center of the Earth, as origin, to a point on the periphery of any of the curves, is proportional to the intensity of magnetization of the equivalent uniform magnetic field at that point, or parallel of latitude. In other words we have in Fig. 1 a graphical representation showing how the intensity of magnetization would have to vary from parallel to parallel to reproduce the Earth's internal magnetic field, symmetrical about the axis of rotation, as represented by the coefficients of the zonal harmonics of the I-system, given in Table 1.

If, for example, there were only the γ^i_{10} term, then there would be a strictly uniform magnetic field and the intensity of magnetization would be the same over the entire sphere; this simple case is represented by the equations for X^i_a and Z^i_a, contained in (1) and (2), and is graphically represented by the outer circle in Fig. 1.

Next suppose that the zonal, or polar, field is not only symmetrical about the axis of rotation, but also about the equator, *i. e.*, let us combine the values of X_a and Z_a into mean values for corre-

sponding parallels, north and south of the equator. Then the coefficients $-\gamma_{20}$, $-\gamma_{40}$, and $-\gamma_{60}$ in Table 1 drop out and we have a magnetic field represented by the zonal coefficients, $-\gamma_{10}$, $-\gamma_{30}$, and $-\gamma_{50}$. This case is represented in Fig. 1 by the ellipses (broken curves) for 1885 and 1922; in other words, for the case considered, whatever are the agencies responsible for the resulting magnetic field, the variation of the physical quantity with latitude would be represented by the radius vector from the center of the Earth to the surface of an oblate ellipsoid of revolution, whose shorter axis is along the axis of rotation of the Earth, and whose ellipticity would be about 30 times that of the Earth. Note that the equivalent intensity of magnetization would increase systematically towards the equator, thus corresponding with our previous deduction (see sec. 6c). Note also that the 1922 ellipse lies inside the 1885 ellipse, which is a graphical representation of the shrinkage in the intensity of the Earth's magnetic field between 1885 and 1922, regarding which more will be said elsewhere.

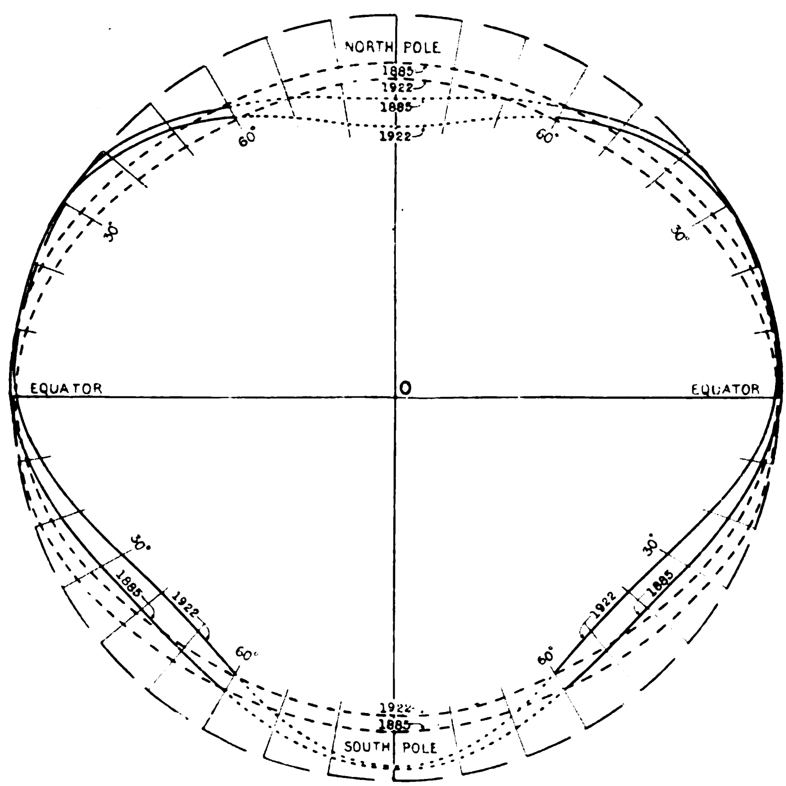

FIG. 1.

9. Next let us take the actual case as represented by all the zonal *I*-coefficients given in Table 1. We then have an internal magnetic field, which, while symmetrical, but not uniform, about the axis of rotation, is not symmetrical about the equator. We shall then get the heart-shaped curves shown in Fig. 1 for 1885 and 1922. The pear-shaped solid, obtained by the revolution of the heart-shaped curve about the Earth's axis of rotation, would give a graphical representation of the volume, or surface distribution, of the physical quantity producing the magnetic field here under consideration. It is clear that no homogeneous spherical iron core inside the Earth could produce such a magnetic field as represented by the zonal coefficients of Table 1. The portions of the curves in Fig. 1, for the regions of the Earth north of parallel 60°N and south of parallel 60°S, are dotted in order to indicate that they have been obtained on the assumption that the zonal coefficients derived from the region 60°N to 60°S (86 per cent of the Earth's surface) also apply to the polar areas, which assumption, while not strictly correct, may be sufficiently so for our general purpose. Comparing the radii vectores for corresponding parallels of latitude, north and south, it is seen that for both curves (1885 and 1922), the lengths, or corresponding equivalent intensities of magnetization, are greater for a land-predominating parallel than for an ocean-predominating parallel. It is not until the polar areas are reached that striking departures from this general rule are apparently observed, but, as a matter of fact, the departures in the polar areas are not contradictions to the general rule. Thus the curves in the Arctic, where ocean chiefly predominates, bend towards the origin, *O*, whereas the curves for the Antarctic, where land is supposed chiefly to predominate, show elongations away from the origin, *O*. In other words, if we compare the polar areas, north and south, it is again found that the equivalent intensity of magnetization is greater over the land polar area than over the water polar area.

It will be seen once more that the 1922 actual curve lies wholly within the 1885 one, the radial difference between the two curves giving a striking graphical representation of the shrinkage in the Earth's intensity of magnetization during the 37-year period. And it should be particularly noted that the radial difference between the two curves is greater, in general, for ocean-predominating parallels, from the North Pole to the South Pole, than for land-predominating parallels.

We have also expressed mathematically the relative distribution

of land and water, from parallel to parallel, by means of zonal harmonics, the coefficients of which show some striking similarities to the corresponding magnetic coefficients in Table 1, but this is a matter reserved for exposition in a future paper.

10. To get some idea as to what the facts just stated may signify, let us recall that the magnetic field, represented by the I zonal coefficients of Table 1, is that portion of the Earth's total internal magnetic field symmetrical about the axis of rotation. There is not included that portion of the Earth's magnetic field responsible for the fact that the compass needle, in general, does not point exactly north or south.

If, then, the distribution of land and water, and consequent distribution of electric conductivity, has such marked effects, as exhibited by Fig. 1, then we may be forced to conclude that the chief agencies responsible for the Earth's internal magnetic field are confined to a layer of average depth of about two miles or less. Hence, the magnetic-field producing agencies may be comparatively close to the surface of the Earth.

If now we imagine these agencies to be equivalent in their action to electric currents or a motion of electricity brought about in some manner, relative to the surface, then we may have to conclude that the deflection of these equivalent electric currents from their normal paths, for example, along a parallel of latitude, is greater, for some reason, over ocean areas than over land areas. The net effect might be a decrease from parallel to parallel in the polar component of the Earth's magnetic field, let us call it c_p, and a more or less corresponding increase in the equatorial component, c_e, in passing from the land hemisphere to the water hemisphere. And this is what actually seems to occur as shown by the values of c_p and c_e for 1885,[1] and again shown for 1922. But the value of $c = \sqrt{c_p^2 + c_e^2}$ is not constant from parallel to parallel, as it should be, approximately at least, if the relative distribution of land and water simply produced an alteration in the paths of possible currents circulating within the Earth's crust; we apparently require also a change in current density.

The foregoing remarks are merely intended to indicate the character of the conclusions we may have to reach with respect to the origin of the Earth's magnetic field. A more critical examination of the possible hypotheses must be left for a future paper.

[1] *Terr. Mag.*, vol. 17 (1912), p. 84. Reference may be made also to some conclusions regarding the effect of distribution of land and water, drawn by Nippoldt from the author's 1885 values of c_p and c_e, given in *Terr. Mag.*, vol. 26 (1921), 101.

11. Before passing to the next topic it will be of interest to state that we have computed from the observed magnetic data for 1922 the equivalent intensity of magnetization for points at intervals of 10° in longitude and 5° in latitude for the region 60°N to 60°S. Though our computations have been made in various ways, we do not find any reason for concluding, as has been done from incomplete investigation, that the ocean beds are more magnetic than corresponding land areas. Our results indicate the converse fact, namely, that *the average equivalent intensity of magnetization over land areas is somewhat larger than the average equivalent intensity of magnetization over ocean areas.*

12. To get some idea of the magnitude of the magnetic components, to be ascribed respectively to the internal and external magnetic fields for 1922, as shown by the 6 coefficients in Table 1, the values of X_a^i, X_a^e, and X_a have been computed (Table 3). It will be seen by glancing down the column, X_a^e, that the value of this component from the external potential may amount to 10 per cent of the corresponding component from the internal field; on the average, not taking account of sign, we have $X_a^i = 0.2391$, $X_a^e = 0.0048$, and $X_a = 0.2437$ C. G. S. Similarly, $Z_a^i = 0.3160$, $Z_a^e = 0.0022$, and $Z_a = 0.3138$. Hence, for the region 60°N to 60°S the external field contributes an X_a component, which on the average is about 2 per cent of the total X_a component, and a Z_a component which, on the average, is about 0.7 per cent that of the total Z_a component.

TABLE 3.—*Computed values of the average components along a parallel of latitude, X_a and Z_a, for 1922 and for the potential systems, internal, external, and combined, in units of the fourth decimal C. G. S.*

Parallel	X_a^i	X_a^e	X_a	Z_a^i	Z_a^e	Z_a
°						
60 N	+1203	+113	+1316	+5249	−61	+5188
50 N	+1762	+ 86	+1848	+4869	−19	+4850
40 N	+2318	+ 58	+2376	+4221	− 4	+4217
30 N	+2796	+ 44	+2840	+3314	− 5	+3309
20 N	+3133	+ 43	+3176	+2203	− 6	+2197
10 N	+3288	+ 45	+3333	+ 975	− 2	+ 973
Equa.	+3244	+ 45	+3289	− 268	+ 6	− 262
10 S	+3023	+ 43	+3066	−1413	+12	−1401
20 S	+2689	+ 42	+2731	−2378	+18	−2360
30 S	+2330	+ 42	+2372	−3143	+27	−3116
40 S	+2021	+ 33	+2054	−3765	+40	−3725
50 S	+1769	+ 13	+1782	−4341	+47	−4294
60 S	+1510	− 13	+1497	−4936	+37	−4899
Av. Val. (Without sign)	2391	48	2437	3160	22	3138

It will be observed that if only the external field existed, the north end of the compass needle would still point to the North, but the dipping needle would have its north-seeking end pointing above the horizon in the North Hemisphere and below the horizon in the South Hemisphere, or just contrary to the action of the internal magnetic field.

13. Now let us get some idea of the accuracy of representation of the observed values of X_a and Z_a for 1922, on the basis of various hypotheses, by tabulating the difference $(O-C)$ between observed

TABLE 4.—*Differences $(O-C)$ between observed and computed components, X_a and Z_a, for 1922, in units of the fourth decimal C. G. S., the computed components being derived according to various hypotheses.*

Parallel	All Int'l Pot'l Systems		Int'l and Exter'l Pot'l Systems			
	7th Har. Incl.		6th Har. Incl.		7th Har. Incl.	
	ΔX_a	ΔZ_a	ΔX_a	ΔZ_a	ΔX_a	ΔZ_a
°						
60 N	−192	−112	−27	−18	− 5	−13
50 N	− 77	+ 5	+16	+10	+ 6	+ 4
40 N	+ 30	− 9	+14	−15	+ 3	− 9
30 N	+122	− 18	− 8	−11	− 2	− 7
20 N	+199	− 4	−15	0	− 4	− 1
10 N	+246	+ 18	+10	+ 7	+ 7	+ 4
Equa.	+199	− 6	+19	−24	+ 6	−24
10 S	+ 49	+ 12	−12	− 8	−16	− 4
20 S	− 84	+ 33	− 9	+ 6	+ 1	+ 7
30 S	−165	+ 35	+ 1	− 5	+ 9	−10
40 S	−161	+ 31	+ 8	−17	− 1	−14
50 S	− 87	+ 51	+ 3	+ 5	− 8	+10
60 S	+ 5	+ 36	−10	− 8	+ 6	−14
Av. Res. (Without sign)	124	28.5	11.7	10.3	5.7	9.3

and computed values, as shown in Table 4. Let us first suppose that X_a and Z_a are derivable from a single potential function arising exclusively from internal systems, as was done by Gauss, for example, and let us expand the potential series to the seventh order harmonic inclusive and thus determine seven zonal coefficients. Then, as will be seen from the second and third columns, not only is the run of the residuals $(O-C)$, both for X_a and Z_a, of a systematic character but they even reach the second decimal C. G. S. We must conclude that the hypothesis of a single potential does not give a satisfactory representation of the observed quantities.

If we assume the existence, both of an internal and an external potential, as represented by the coefficients of Table 1, it will be

seen from the fourth and fifth columns of Table 4 that a much more satisfactory representation is now obtained, although the expansion is carried only to the harmonic of sixth degree. If we include the harmonic of seventh degree then a still better representation is obtained (see last two columns of Table 4).

Our general conclusion is that the assumption of both an internal and external magnetic system is necessary to secure a satisfactory representation of the observed magnetic data, X_a and Z_a. (*Cf.* §31.)

14. *Average non-potential field.* If the average magnetic components for parallels of latitude could be represented wholly satisfactorily by an internal potential and an external potential, derived from X_a and Z_a, as shown by the coefficients in Table 1, then should Y_a, the average of the Y, or east-west, component along a parallel of latitude, vanish within the observational error for each parallel. In other words, the compass needle should theoretically point truly north and south everywhere, but this does not appear to be the case. Even were we to eliminate from the total magnetic field all the portions that may be accounted for by an internal potential system and an external potential system, we still apparently find a directive force (about 3 per cent of the total, or about equal to that of the external potential system) which sets the compass needle in an approximate north-south direction. On the average between 5° and 45°N, the north end of the compass needle would point approximately 0.°1 east of North, and for the corresponding region in the South Hemisphere about 0.°1 west of North. This outstanding portion of the Earth's total magnetic field is designated as the non-potential portion, N; its effects, as known, are disclosed by line-integrals of the magnetic force around a closed path on the Earth's surface, and we have already given various results of such line-integral computations.[1]

If the closed path be a parallel of latitude, then the value of the line-integral is indicated by the value of Y_a. While the preliminary values of Y_a for 1921, as resulting from the latest 1920 and 1922 charts of the lines of equal magnetic declination, are now, on the average, smaller than for previous charts, they still show a general systematic run, difficult to explain wholly by observational error. Thus for the region 5°N to 45°N, the sign of Y_a is persistently positive, and for the corresponding region in the South Hemisphere, it is persistently negative. The average value of Y_a, for the region stated in each hemisphere, is about 0.0004 C. G. S. Perhaps

[1]See, for example, *Terr. Mag.*, vol. 25 (1920), 145-162.

the actual existence of a non-potential field will become still more evident from the results in the next sections. (*Cf.* §§19, 20, 21, 32, and 33.)

EARTH'S UNIFORM MAGNETIC FIELD PARALLEL TO AN INCLINED DIAMETER.

15. *X, Y, Z systems.* Let us at first make no assumption as to the composition of the total magnetic field, and treat X, Y, Z, as independently of one another as the imposed conditions permit. The first step, as usual, is to represent the values of X, Y, Z by Fourier series for each parallel, λ being the longitude, counted positive east from Greenwich, of the point considered. Thus:

$$X = X_a + k_1 \cos\lambda + K_1 \sin\lambda + k_2 \cos 2\lambda + K_2 \sin 2\lambda + \ldots\ldots \quad (3)$$
$$Y = Y_a + l_1 \cos\lambda + L_1 \sin\lambda + l_2 \cos 2\lambda + L_2 \sin 2\lambda + \ldots\ldots \quad (4)$$
$$Z = Z_a + m_1 \cos\lambda + M_1 \sin\lambda + m_2 \cos 2\lambda + M_2 \sin 2\lambda + \ldots\ldots \quad (5)$$

From the 25 values (5° parallels, 60°N to 60°S) for each of the unknowns k, K, l, L, m, M, the respective Gaussian coefficients were derived by least squares, in general accord with the method adopted by Adolf Schmidt for 1885. Table 5 gives the first degree harmonic, *i. e.*, for the first three terms of each series, (3), (4), and (5), both for 1885, based on Schmidt's figures, and for 1922, according to our calculations. The publication of the coefficients of the other harmonics is at present deferred.

TABLE 5.—*Uniform portion of Earth's X, Y, and Z magnetic systems for 1885 and 1922, and average annual changes, derived from region 60°N to 60°S.*

Quantity	1885			1922			An. Ch. (1922-1885)		
	X	Y	Z	X	Y	Z	dX	dY	dZ
	c.g.s.	c.g.s.	c.g.s.	c.g.s.	c.g.s.	c.g.s.	°/o	°/o	°/o
$c_p = M_p/R^3$	+.31918	....	+.31513	+.30992	....	+.30084	−0.08	......	−0.12
$c_e = M_e/R^3$	.06367	.06324	.06449	.06303	.06235	.06113	−0.03	−0.04	−0.14
$c = M/R^3$	.32547	....	.32166	.31626	....	.30699	−0.08	......	−0.13
ϕ_n	78°43′.1 N	....	78°26′.0 N	78°30′.2 N	....	78°30′.9 N	0′.35 S	......	0′.13N
λ_n	71 30 W	69°32′W	67 31 W	72 11 W	67°59′W	68 38 W	1.11W	2.51 E	1.81W

The quantities in Table 5 have the following significance:
M = Earth's magnetic moment; R = Earth's mean radius;
M_p = Component of M along axis of rotation, or polar component;
M_e = Component of M perpendicular to axis of rotation, or equatorial component;

c_p, c_e, and c are proportional, respectively, to the corresponding components of magnetization, and to the resultant;

$$c_p = -g_{10} = -\sqrt{3}\,.\,\gamma_{10} \text{ (see Table 1)};\ c_e = \sqrt{(-g_{11})^2+(-h_{11})^2};$$
$$c = \sqrt{c_p^2 + c_e^2}\ ;$$

ϕ_n = latitude of north end of magnetic axis, calculated from the formula, $\tan \phi_n = c_e/c_p$;

λ_n = longitude of north end of magnetic axis, calculated from the formula, $\tan \lambda_n = (-h_{11})/(-g_{11})$.

16. *The following are the main conclusions to be drawn from Table 5:*

a. For all three systems, X, Y, and Z, the magnetic moment, as well as each of its components, has diminished since 1885, the vertical system (Z) having diminished in strength at a more rapid rate than the horizontal systems (X, Y).

b. The north end of the magnetic axis of the X-system has moved since 1885 towards the equator at the average annual rate of about one-third of a minute, whereas that of the Z-system has moved towards the North Pole at a less rapid rate, namely, at an average annual rate of one-eighth of a minute of arc.

c. While the north end of the magnetic axis, for both systems, X and Z, has moved since 1885 towards the west, at the average annual rates of 1.′1 and 1.′8, respectively, the north end of the magnetic axis of the system chiefly responsible for the changes in the magnetic declination, the Y-system, has moved since 1885 at the average annual rate of 2.′5 towards the east.

d. The above conclusions show the complex nature of the various magnetic systems composing the uniform portion of the Earth's magnetic field, as well as the complicated character of the secular magnetic changes.

17. *I and E systems.* From the X, Y, Z systems, the coefficients of which are given in Table 5, we may pass, by the usual process, to the two potential systems, internal (I), and external (E). The coefficients for the first harmonic term of the two systems, I and E, are given in Table 6 for three epochs, 1842, 1885, and 1922. The 1922 quantities are to be regarded as preliminary ones and subject to some slight changes dependent upon further computations in progress. Except for the effect of errors in the 1885 magnetic charts, especially over the ocean areas, the 1922 and 1885 results would be strictly comparable. The method of analysis adopted by Adams and Fritsche and the region of Earth embraced for the epoch 1840-45, are somewhat different from those for 1885 to 1922.

TABLE 6.—*Uniform portion of the Earth's internal* (*I*) *and external* (*E*) *magnetic systems, 1842-1922.*

Quantity	Adams, Fritsche 1842		Schmidt 1885		Dept. T. M. 1922		Int'l Syst. An. Change	
	I	E	I	E	I	E	1842–1922	1885–1922
	c.g.s.	c.g.s.	c.g.s.	c.g.s.	c.g.s.	c.g.s.	°/°	°/°
$-g_{10}=c_p=M_p/R^3$	+.32169	+.00202	+.31733	+.00186	+.30468	+.00523	−0.07	−0.11
$-g_{11}$	+.02760	−.00017	+.02356	−.00241	+.02202	−.00069	−0.28	−0.18
$-h_{11}$	−.05826	−.00146	−.05984	+.00004	−.05776	−.00113	+0.01	−0.09
M_e/R^3	.06447	.00147	.06431	.00241	.06182	.00132	−0.05	−0.10
M/R^3	.32809	.00250	.32378	.00304	.31089	.00539	−0.07	−0.11
ϕ_n	78°40′ N	53°.9 N	78°32′ N	37°.6 N	78°31′.9 N	75°48′ N	0′.10 S	0′.0
λ_n	64 39 W	92.6 W	68 30 W	180.9 W	69 08 W	121 24 W	3.38W	1.0W

The average annual changes are worked out only for the *I*-system, as the data for the *E*-system for the epochs 1842 and 1885 may be subject to considerable uncertainty, on account of the known imperfections, or incompleteness, of the earlier magnetic charts on which the analyses for those years had to be based. The significance of the quantities in Table 6 has already been explained in §15.

18. *The chief conclusions to be drawn from Table 6 are:*

a. The portion in 1922 to be referred to an external magnetic potential is nearly three times that apparently shown by the earlier analyses. It is at present believed that this result is to be ascribed chiefly to improved knowledge of the Earth's magnetic field, especially over the oceans, rather than to secular change.

b. For 1922 the north end of the magnetic axis of the *E*-system is somewhat south and about 52° *west* of the axis of the *I*-system. It may be of interest to note in this connection that the displacements in longitude of the north ends of the *I*-axis and of the *E*-axis are of about the same amount (26°), as referred to the position of the Magnetic North Pole, the displacement of the *I*-axis being towards the east of the M. N. P., and that of the *E*-axis towards the west. (What reliance may be placed on the indicated positions of the *E*-axis for the earlier analyses, it is difficult to say, because of well-known errors in the earlier magnetic charts.)

c. It would seem to be fairly well established now that both the polar and the equatorial components of the Earth's magnetic moment have been decreasing during the past sixty years. Between 1885 and 1922 the annual decrease in both components has been apparently as much as one-tenth of one per cent.[1]

d. The indications are that the north end of the magnetic axis of the *I*-system, besides moving westward with the lapse of time, may also be slowly moving towards the equator. (Were the west-

[1] *Cf.* previous results in *Terr. Mag.*, vol. 8 (1903), 97-108, and particularly vol. 9 (1904), 173-186.

ward motion to continue at the same rate as that shown between 1885 and 1922, it would take over 20,000 years to accomplish a complete revolution of the magnetic axis around the axis of rotation. Were the average rate of westward motion to continue as apparently shown between 1842 and 1922, the complete revolution of the magnetic axis would take about 6,400 years. However, we have as yet no reliable evidence that the magnetic axis will make such a complete revolution. In fact such evidence as there is at present indicates the contrary fact. For all we know, the magnetic axis of the internal potential system may have been nearer coincidence with the axis of rotation than it is now, and for many centuries while slowly turning towards the west, but not making a complete revolution, it may have been slowly moving towards the equator in consequence of induced demagnetizing systems.)

Fig. 2 shows the positions for 1922 of the north end of the magnetic axis ($M\,A$) of the I-system and of the E-system, and that of the Magnetic North Pole, according to the best evidence at hand. As will be seen, the line of maximum auroral frequency passes to the south of the three positions.

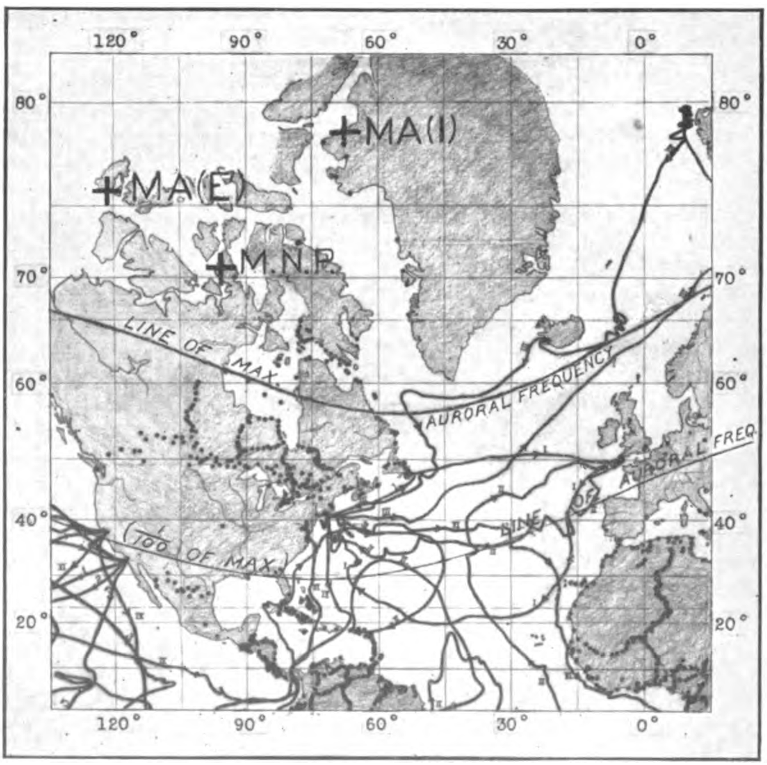

FIG. 2.

FURTHER EVIDENCE OF A NON-POTENTIAL SYSTEM.

19. It is found that the total magnetic field, made up of the three systems (X, Y, Z), cannot be represented satisfactorily solely by an internal potential system plus an external potential system. In other words we must introduce a third system, not having a magnetic potential, the N-system. To show this, Table 7 has been prepared, referring to the coefficients of the sin λ and cos λ terms in formulas (3), (4), and (5); the same evidence presented in this table could readily be extended to the successive terms (multiples of λ).

TABLE 7.—*Average residual $(O-C)$ for 1922 in units of fourth decimal C. G. S., for k_1, K_1, l_1, L_1, m_1, and M_1, and region 60°N to 60°S.*

No.	k_1	K_1	l_1	L_1	m_1	M_1	Method of computation	
1	15.5	23.3	13.5	13.6	27.8	26.5	All internal pot'l; XYZ combined;	7° har.
2	11.9	6.8	5.4	9.3	....	....	Hor'l potential; XY combined;	7° har.
3	16.5	10.5	6.2	11.2	....	....	Hor'l potential; XY combined;	6° har.
4	28.9	24.4	2.4	3.5	....	....	Y—potential; Y alone;	6° har.
5	9.5	7.8	4.1	5.1	23.7	20.1	3 distinct systems, X, Y, Z separate;	6° har.

The first line shows the average value of the residual $(O-C)$, regardless of sign, between observed and computed value of the designated coefficient, derived on the assumption that the X, Y, Z quantities are the partial derivatives of a single potential function; to make the case as favorable as possible, the potential series was expanded to include the harmonic of the seventh degree. It will be seen that even the average residuals, for the whole region 60°N to 60°S, reach the third decimal C. G. S.

The second and third lines contain the values of $(O-C)$, assuming merely that the horizontal components X, Y are the derivatives of a single potential function, first taking harmonics to the seventh degree inclusive, and second, taking harmonics to the sixth degree inclusive. While there has thus resulted some improvement in the residuals for k_1, K_1, l_1, and L_1, some of the average residuals still reach the third decimal C. G. S.

Of the three components X, Y, Z, Y may be represented by a potential series with the highest degree of accuracy. Let us, therefore, obtain the tesseral Gaussian coefficients alone from the assumed Y-potential. On this basis, even though the expansion be carried only to the sixth-order harmonic, we get average residuals for l_1 and L_1 amounting only to a few units in the fourth decimal

C. G. S. But now let us apply the Y-coefficients, thus derived, to the X, or north component, and we find that they will not fit, the average residual for k_1 and K_1 being nearly 0.003 and 0.0025, respectively. In other words, the values of both X and Y cannot be represented satisfactorily by a common magnetic potential, composed of internal and external potential systems; it is necessary to assume an additional system not having a potential. (That the coefficients derived from the Y-components will not represent the X-components satisfactorily, has been the common experience of several investigators who during recent years have investigated the diurnal variation of terrestrial magnetism.) Whatever the proper interpretation of the non-potential effects may be found to be, we apparently cannot escape the probable existence of a non-potential magnetic system. (*Cf.* §§32 and 33.)

20. *Three systems, I, E, and N.* Now coming to the last line of residuals, we have the values obtained by treating X, Y, Z as separately as possible; in other words, provision is made for the co-existence of three systems, I, E, N. On the whole, we now get the best set of average residuals, though those for l_1 and L_1 are somewhat larger than the corresponding ones for No. 4, the extent of expansion of the harmonic series being the same in both cases. The reason is that according to Schmidt's method it is not possible to make a wholly independent adjustment of the X and the Y equations, and consideration is being given at present to modifications of method which may accomplish the desired purpose. As pointed out in a previous paper by the author,[1] Schmidt was likewise not wholly successful in the mathematical representation of the Y-components for 1885 by his method of adjustment. Schmidt deserves high credit, however, for development of a method of analysis, which was a great improvement over that of his predecessors.

21. Table 8 will give some idea of the relative amounts to be attributed to the component systems which together make up the coefficients k_1, K_1, l_1, and L_1. Thus the average magnitude of k_1^i, on account of the internal magnetic potential, is 0.0304 C. G. S., that of k_1^e, caused by the external magnetic potential, is 0.0014 C. G. S., and finally that of the non-potential system, k_1^n, is 0.0027 C. G. S. Thus the external system and the non-potential system, together, may at times contribute ten per cent or more to k_1. The same is

[1] *Terr. Mag.*, vol. 8 (1903), 118-129.

true with regard to K_1 and L_1. For l_1 the contribution of the E and the N systems may be five per cent or more.

TABLE 8.—*Average numerical values for 1922 and region 60° N to 60° S of component parts of k_1, K_1, l_1, and L_1, in units of fourth decimal C. G. S.*

$k_1^i = 304$	$K_1^i = 377$	$l_1^i = 562$	$L_1^i = 299$
$k_1^e = 14$	$K_1^e = 12$	$l_1^e = 13$	$L_1^e = 10$
$k_1^n = 27$	$K_1^n = 16$	$l_1^n = 11$	$L_1^n = 20$

22. *Is* $\int d\mu = o$? We must confess to a sense of disappointment with regard to the average residuals for the coefficients m_1 and M_1, for case No. 5, Table 7. While there is some improvement over the corresponding ones in No. 1, and while they may be somewhat further reduced by including another harmonic term so as to have the same number of coefficients as in No. 1, there is evidence of some other outstanding phenomenon. All analysts, beginning with Gauss, have assumed that $\int d\mu$ is zero, where $d\mu$ represents the elemental quantity of magnetism; these elemental magnetic quantities being both plus and minus, the integral was taken as zero. Of course $d\mu$ might stand for some other physical quantity than the one stated. The assumption of the integral being zero affects the Z-series, but not the series for X and Y, provided there are only systems having a magnetic potential. If we do not assume that the integral is zero, in view of the various systems entering into the composition of the Earth's total magnetic field, or because of the fact that our analysis is not based on magnetic data over the *entire* Earth, then a constant term enters into the Z-expression, which, if introduced, further reduces the average residuals of m_1 and M_1. Furthermore, if there is also a non-potential system, caused, for example, by vertical electric currents, then the mathematical expressions for X and Y would likewise be affected by the non-fulfillment of the assumption $\int d\mu = 0$, as the question would arise, whether for the region considered, the total amount of electricity entering the Earth equals the total amount emerging from the Earth. It is of interest to note that Gauss himself in his celebrated memoir, section 35, intimated that the day might come when it could no longer be assumed that the integral of $d\mu$ is zero.

THE EARTH'S TOTAL MAGNETIC ENERGY.

23. The Earth's magnetic moment, as defined by Gauss, pertains only to that portion of the Earth's internal magnetic field expressed by the first harmonic, and hence represents a uniform magnetization parallel to a diameter, the north end of which in 1922, according to Table 6, was in latitude 78°31.′9N, and longitude 69°08′W. The question arises whether the large annual decrease in the magnetic moment, as already described, is in any measure compensated by an increase in the non-uniform, or heterogeneous, portion of the Earth's total internal magnetic field.

To obtain a measure of the Earth's *total* internal magnetic field, I used in 1903, for the first time in terrestrial magnetism, the "magnetic energy" of the field; for details and development of formulæ the interested reader may be referred to the 1903 paper.[1]

Let W be the magnetic energy of the Earth's total internal magnetic field at any point in space, F, the corresponding field intensity at that point, and $d\tau$, the element of volume, and let us set the magnetic permeability for the space outside the Earth equal to unity, then.[2]

$$W=\frac{1}{8\pi}\int F^2 d\tau=\frac{1}{8\pi}\int_0^{2\pi}\int_0^{\pi}\int_R^{\infty}(X^2+Y^2+Z^2)\,r^2\sin u\,d\lambda\,d u\,d r,$$

$$=R^3\left[(\gamma^2_{10}+\gamma^2_{11}+\eta^2_{11})+\tfrac{3}{2}(\gamma^2_{20}+\gamma^2_{21}+\eta^2_{21}+\gamma^2_{22}+\eta^2_{22})+\text{etc.}\right]$$

$$=R^3\,]\mathrm{I}+\mathrm{II}+\mathrm{III}+\mathrm{IV}+\text{etc.}]$$

The quantities γ, η are the Gaussian coefficients, using Schmidt's functions, and R is the Earth's mean radius. It is found that it suffices for our purpose to stop with term IV, representing the fourth degree harmonic. Term I refers solely, as in the case of the magnetic moment, to the first harmonic, or uniform portion of the internal magnetic field.

Table 9 gives a comparison of the results for 1885 and 1922, the 1885 quantities being taken from the 1903 paper:[3]

TABLE 9.—*Values of W/R^3 for 1885 and 1922, in C. G. S. units.*

Epoch	Unif. Portion	Non-Uniform Portion				
	I	II	III	IV	II+III+IV	Total
1885	0.03495	0.00034	0.00015	0.00004	0.00053	0.03548
1922	0.03222	0.00038	0.00016	0.00006	0.00060	0.03282

Average annual decrease of W/R^3, 1885 to 1922 = 0.000072 = 0.211 per cent, or about 1/474 part.

[1] *Terr. Mag.*, vol. 8 (1903), 98-111. [2] *Idem*, 100-103. [3] *Idem*, p. 107.

From the 1903 computations it was found that the average annual decrease in the magnetic energy during the forty-six years, 1838 to 1884, was 0.0626 per cent, or about 1/1,600 part. Hence, the average annual decrease in the magnetic energy of the Earth's internal magnetic field, for the region 60°N to 60°S, appears to have been about 3 times as rapid between 1885 and 1922 as it had been during the 46 years prior to 1885. Whether this is because of the greatly improved ocean data on which the 1922 charts are based, must be left for a future investigation.

24. It will be of interest to give in detail the computation of the magnetic energy of the uniform portion of the Earth's internal magnetic field, as the loss in magnetic energy is practically confined to this portion.

TABLE 10.—*Value of W/R^3 for uniform portion of Earth's internal magnetic field, in C. G. S. units.*

Epoch	Polar Component	Equatorial Component	Total
1885	0.033566	0.001379	0.034945
1922	0.030944	0.001274	0.032218
Total decrease........	0.002622	0.000105	0.002727
Average annual decrease	0.220%	0.214%	0.220%

The figures in this table show that for the period 1885 to 1922, and for the region of the Earth 60°N to 60°S, the average annual decrease in the magnetic energy of the uniform portion of the Earth's internal magnetic field was practically the same, namely about one-fifth of one per cent, or about 1/500 part, for both the polar component, parallel to the axis of rotation, and the equatorial component, perpendicular to the axis of rotation.

For the uniform portion of the internal magnetic field the relation between the magnetic energy, W, and the magnetic moment, M, is[1]

$$W = M^2/3\,R^3,$$

$$\text{Hence, } d\,W/W = 2\,d\,M/M. \qquad (7)$$

Since $d\,W/W$ was found to be equal to about 1/500 part, the corresponding average annual decrease in M, between 1885 and 1922, was about 1/1,000 part, as already stated. The average annual loss of the magnetic moment of well-seasoned magnets is about 1/500 part. In 1918 I found that an increase of 100 in the sun-spot

[1] *Terr. Mag.*, vol. 26 (1921), 54.

number was accompanied, during 1891-1916, by a decrease of about 1/1,000 part in the Earth's magnetic moment.[1]

From the foregoing sections, it is seen that, in view of the complexity of the Earth's magnetic field and the rather large annual decrease in the magnetic moment, or in the equivalent intensity of magnetization, it is a doubtful procedure to determine, as has actually been attempted, the Earth's magnetic potential for epochs prior to the nineteenth century, for which only declination and inclination observations are available.

THE EARTH'S SECULAR-VARIATION SYSTEM.

25. If we inquire into the general character of the secular-variation system, which superposed upon the uniform internal magnetic field for 1885, gradually changes the latter into the internal uniform magnetic field for 1922, shown in Table 6, it is found that the secular-variation system is a de-magnetizing system, whose magnetic axis is directed almost diametrically opposite to that of the primary uniform field. This is in harmony with the general deduction from the 1904 computations,[2] which pertained to the average annual secular-variation system between 1890 and 1900, as based on actual observational material.

If the internal de-magnetizing system is the result of self-induction, due to one cause or another, as, for example, relative motion of the component parts of the Earth's total field, with reference to one another, then it must be borne in mind that the total system at any one time is itself a composite one made up of the total actual primary system plus the total induced system. It will require considerable further investigation before an attempt to separate the total existing system into a primary and an induced one can be safely undertaken.

26. After the total observational material has been carefully referred to common epochs, we are planning, if it is found possible, to make an analysis of the Earth's magnetic field for 1913, the year of minimum sun-spot activity; for 1917, the year of maximum sun-spot activity, and again for subsequent similar epochs.

There would hardly seem to be any question now, as already concluded in my 1904 paper,[2] that "*the secular variation of the Earth's magnetism is caused not only by a change in the direction of magnetization, but likewise by a change in the intensity of magnetization.*"

[1] *Terr. Mag.*, vol. 23 (1918), p. 63. [2] *Terr. Mag.*, vol. 9 (1904), 186.

SUMMARY OF CHIEF CONCLUSIONS.

27. The chief conclusions reached in the present paper are as follows:

a. It is necessary to recognize that the Earth's total magnetic field at any one time is apparently composed, to the extent of about 94 per cent, of an internal magnetic potential system, *I*, and to the extent of about 6 per cent, of an external magnetic potential system, *E*, plus a non-potential system, *N*. (There is a possibility that relativity effects may play a part in the exact evaluation of the three systems.[1])

b. Instead of the three systems, *I*, *E*, *N*, the exact evaluation of each of which rests somewhat on assumption as to the character of the causes producing the observed magnetic field of the Earth, we may say that in order to represent satisfactorily the observed magnetic data, it is necessary to recognize the existence of three distinct systems, namely, the *X*, *Y*, *Z* systems. The *X*-system is responsible for the total component acting on the magnetic needle in the direction positive towards geographic North; the *Y*-system, for the total component in the direction positive towards geographic East; and the *Z*-system, for the total component acting in the vertical direction positive towards the nadir.

c. It must be recognized that the magnetic secular-variation system is as complex as the Earth's total magnetic field existing at any one time, and that in addition to changes in the direction of magnetization with the lapse of time there is also a change in the average equivalent intensity of magnetization. The magnetic axis of one component of the total secular-variation system may show a reverse motion in latitude and longitude to that shown by another component. On the whole, as a resultant effect, it would seem that the north end of the axis of the Earth's internal magnetic field during the past 80 years has been moving slowly towards the west, and apparently at the same time slowly towards the equator. It is not possible to speak at present of any period of complete revolution of the magnetic axis about the Earth's axis of rotation. (Were the average annual rate of motion of the magnetic axis, as indicated during the past 80 years, to continue unaltered, a complete revolution would require about fifteen thousand years, or more. Shorter periods deduced from analyses in which no account is taken of possible change in intensity of magnetization, besides change in direction of magnetization, or obtained from a discussion of the secular change in limited regions of the globe, evidently cannot be regarded as pertaining to the Earth's field as a whole.)

d. The average equivalent intensity of magnetization of the Earth has been steadily diminishing during the past 80 years at the average annual rate of about 1/1500 part. How long it will continue to diminish, whether there will be a time of no change, or whether it will later increase, are questions that cannot be answered

[1] *Terr. Mag.*, vol. 17 (1912), 96.

at the present time. (Whether the annual rate of loss is actually variable, as would apparently be indicated on the basis of the magnetic charts of 1885 and 1840-1845, is another matter which must await completion of additional analyses to be made for epochs for which magnetic data of known reliability are available.)

e. A suggestive effect, dependent apparently upon the distribution of land and water, has been disclosed, namely, that the average equivalent intensity of magnetization for corresponding parallels north and south, is generally larger for the land-predominating parallel than for the ocean-predominating parallel.

f. For 1922 we have for the Earth's uniform internal magnetic field, as deduced from magnetic observations over 86 per cent of the Earth's surface (60°N to 60°S), the following data, which it is expected will be only slightly modified by the final analysis, R being the Earth's mean radius (6.37x10^{8}cm.):

M_p = Component of magnetic moment parallel to axis of rotation
$= 0.3047R^3 = 7.88\text{x}10^{25}$ C. G. S.

M_e = Equatorial component of magnetic moment
$= 0.0618R^3 = 1.60\text{x}10^{25}$ C. G. S.

M = Resultant magnetic moment[1] $= 0.3109R^3 = 8.04\text{x}10^{25}$ C. G. S.

$M_p = 4.93\ M_e$.

If the Earth's magnetism were distributed uniformly throughout its volume, as it probably is not, the average intensity of magnetization would be 0.074 C. G. S. The magnetic axis intersects the North Hemisphere in latitude 78°32′N and longitude 69°08′W of Greenwich.

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Appendix.

CONCERNING EXISTENCE OF EXTERNAL AND NON-POTENTIAL SYSTEMS.

28. As the Journal is passing through the press there comes to my attention an article, "The Earth's Magnetic Potential," by Sir Frank Dyson and Mr. H. Furner,[2] which also contains the results of an analysis of the Earth's magnetic field for 1922. The authors state that their analysis is based on the British Admiralty charts for 1922, with some revisions since publication, "using all available material, the greatest source being the observations made by the *Carnegie* and the land observations of the Carnegie Institution." Their Tables I, II, and III contain, respectively, the components Y, X, and Z, derived from the chart values of the declination, horizontal intensity, and dip for the intersections of the 10° parallels and meridians from 80°N to 80°S. The authors of course

[1] The value of the magnetic moment frequently found in text books, as dependent on Gauss's analysis for 1830, is 8.55x10^{25} C. G. S. The average annual rate of loss between 1830 and 1922 is about 1/1500 part, thus corresponding with the average annual rate given in conclusion *d*.

[2] *Mon. Not. Roy. Astr. Soc.*, Geophysical Supplement, vol. I, No. 3, May, 1923, 76-88.

intend that the quantities in these tables shall be regarded as preliminary ones, pending final and accurate reduction of the observations to a common epoch by the Department of Terrestrial Magnetism. This is especially true for the tabulated quantities applying to parallels 80°N, 70°N, 70°S, and 80°S, for which the authors find large residuals when their quantities are compared with the theoretically-computed values. Until we have more magnetic data than at present, for the polar areas, and especially more accurate knowledge of the secular changes, it is safer to confine an analysis of the Earth's magnetic field to the region 60°N to 60°S, as has been done in my paper (§ 4).

29. Taking the Earth as a sphere, the authors establish three separate spherical harmonic series for the three components, X, Y, Z, assuming each component to be the partial derivative of a potential function. The Gaussian coefficients for each of the three series are derived from the entire tabulated data 80°N to 80°S, and in the case of the Z-series, also for the data 60°N to 60°S. They next take weighted means of the coefficients for X and Y, and obtain one combined series as though X and Y resulted from a common potential of a horizontal system of forces. Later, they also exclude the hypothesis of a possible external system. Their method of analysis is accordingly not as free from assumptions regarding the possible constitution of the Earth's magnetic field as that followed by Schmidt and myself.

Including the extreme parallels 70° and 80°, the authors obtain for the value of the chief zonal coefficient, g_1^0 or my $(-g_{10})$, $+0.3095$ from X and $+0.3046$ C. G. S. from Z. Excluding next the doubtful parallels, they obtain for the region 60°N to 60°S a value of $g_1^0 = +0.3000$, differing from the value for 80°N to 80°S by 0.0046 C. G. S. Owing to such differences the authors conclude that there is no sure indication of a system of magnetic forces above the Earth's surface. It would be a matter of great theoretical interest if the data utilized, indeed, warranted stating definitely that g_1^0 from the Z, or vertical component, is altered by as much as 1.5 per cent, accordingly as it is derived from the region 60°N to 60°S, or from the region 80°N to 80°S. My own contention (§4) would thereby be greatly strengthened, namely, that the Gaussian coefficients are to be regarded at first as purely empirical quantities and hence strictly applicable only to the region of the Earth from which they are derived. But the use of data from the high parallels makes the authors' conclusion less convincing. In fact they state (p. 88) that "in the vertical force the discordances (between their observed and formula values) are very large in high latitudes and considerable everywhere."

30. The authors next compute the components X, Y, Z, on the assumption that they are to be attributed to a magnetic potential derived from the combined XY, or horizontal system, of forces as stated in §29, and then form residuals (observed—formula), not only for X and Y, but also for Z. They have excluded the hy-

potheses of an external system and of a non-potential system, and have thus made an extremely interesting experiment. In Table 11 are given the average residuals, regardless of sign, of X, Y, and Z, derived from the authors' tables on pages 85-87 of their paper, first (I) for region 60°N to 60°S, and next (II) for region 80°N to 80°S.

Table 11.—*Average residuals, regardless of sign, in units of third decimal C. G. S., and in percentages of absolute values of X, Y, and Z.*

Component	Region I		Region II	
	60°N – 60°S		80°N – 80°S	
	c.g.s.	%	c.g.s.	%
X	2.8	1	4.0	2
Y	3.0	6	3.8	7
Z	10.1	3	23.2	6

The general increase of the average residuals, especially for Z, when the region embraced is extended to 80°N and 80°S is at once seen. Furthermore, from the percentage columns, it appears that the representation of the Y-components by the authors' method is relatively much inferior to that for the X-components. In brief we are forced to conclude from the authors' residuals that it is not possible to get an equally satisfactory representation of both X and Y by assuming the existence of only a potential system. (*Cf.* §19.)

31. Next in Table 12 will be found the average Z-residual for each parallel 80°N to 80°S, taking now account of sign.

Table 12.—*Average Z-residual, taking into account sign and expressed in units of third decimal C.G.S.*

N 80°	70°	60°	50°	40°	30°	20°	10°	Eq.	10°	20°	30°	40°	50°	60°	70°	80°S
−47	−34	−23	−11	−6	−5	−3	0	0	+4	+7	+10	+11	+16	+13	−32	−74

Note the large residuals especially for the parallels 80° and 70°, in both hemispheres; excluding these uncertain parallels, it is seen that the average residual is systematically minus north of the equator, systematically plus south of the equator, and diminishes, in both hemispheres, systematically towards the equator. In brief this system of Z-residuals is precisely similar to the effects from a magnetic system *above* the Earth's surface; see for example, my Table 3, section 3, column Z'_a. Thus the authors' results prove that it is not possible to get a satisfactory representation of the Earth's magnetic field by the assumption of only internal magnetic systems. As I have already stated in my conclusion, §27*b*, we must either assume 3 distinct systems, I, E, N, or consider the X, Y, and Z systems, as each representing a distinct system of magnetic and electric forces.

32. *Line integrals of the magnetic force.* By taking line integrals of the magnetic force along parallels of latitude, 50°N to 50°S, the authors obtain results which they say are "in general accordance with Professor Bauer's conclusions (*Terrestrial Magnetism*, vol. 25, 1920, p. 153) of upward vertical currents of (positive) electricity around the poles and downward currents in the tropics of the order of about 10 milliamperes per square kilometer." They next take the integrals "round contours extending from latitude 30°N to 30°S and each 60° in longitude." Now because the results of these different areas do not accord well, they conclude that the results "cannot be said to afford confirmation of the general result." The authors apparently expected to find a symmetrical distribution of possible vertical currents around the axis of rotation, which, of course, need not be the case, nor is it found to be the case. It should also be pointed out that a line integral may be zero, or a very small quantity, either for the case of no vertical currents flowing through the area enclosed, or for the case that there is a balancing of all the upward and downward currents in the region. We computed in 1922 line integrals of the magnetic force for circuits of the *Carnegie* in various latitudes and made under various conditions. The results obtained were in general harmony with our previously announced conclusions.[1]

33. At the British Geophysical Meeting on March 5, 1923, Sir Arthur Schuster raised a very interesting point, namely, "that he did not know that any one had verified that the magnetic force was accurately at right angles to the current which produced it." He said further that he had "very recently met the statement that, according to Einstein's theory, the force and the current should not be exactly at right angles."

Non-zero values of line integrals of the magnetic force around a closed circuit can be obtained, either if there is an unbalanced vertical flow of electricity through the area enclosed, or by any cause which would systematically deflect a compass needle in such a manner as to leave an uncompensated amount after the circuit had been traversed.

If the origin of the Earth's internal magnetic field is to be referred to electric currents circulating within the Earth's crust, then, according to the classical theory, a compass needle would always set itself at right angles to the current. Or, if we went completely around the Earth always in the direction at right angles to the compass needle, then we would ever follow an equipotential line or the path of the electric current causing the magnetic field. And if the electric current nowhere cut the Earth's surface, we ought, under the supposition made, return at the end of the journey to our starting place. If, on the other hand, the compass needle, taking into account possible relativity effects, does not set itself precisely at right angles to the electric current, but differs by a trifling amount

[1]LOUIS A. BAUER AND W. J. PETERS: Line integrals of the Earth's magnetic force around ocean areas, *Carnegie Institution Year Book* for 1922, pp. 296-297.

from perpendicularity, then at the end of the supposed journey around the Earth we would not return to our exact starting place. The distance apart between starting (S) and ending (E) place is a measure of the lack of fulfillment of the classical law of perpendicularity of compass-direction to electric current, or is a measure of electric currents which pass perpendicularly through the surface between the North Pole and our path around the Earth. Furthermore, from the fact that E is either north or south of S, we can determine the direction of deviation of the compass needle from perpendicularity, whether east or west of north, or the direction of the currents, whether upwards or downwards, of the vertical current-system. If I recall rightly, this method of testing the existence of vertical currents, or of equivalent effects, was first suggested by Sir Arthur Schuster.

Mr. W. J. Peters, of the Department of Terrestrial Magnetism, has constructed the paths which would be followed in going eastwardly around the Earth always at right angles to the compass direction as indicated by the British Admiralty charts of the lines of equal magnetic declination for 1922. Five circuits were made, starting out each time from the meridian of Greenwich, first at 50°N, next 20°N, third at the equator, fourth at 20°S, and fifth at 50°S. The lack of closing of circuit, that is the difference $S-E$ was found to be of such a systematic character, E, on the average, falling about 30 statute miles north of S, that some explanation would appear to be called for regarding the correctness of the of the charts, if a non-potential system does not exist. This matter will be treated more fully in a separate paper.

At present I see no reason for altering any of the conclusions announced under §27. In fact, the results from the analysis of the Earth's magnetic field by Sir Frank Dyson and Mr. Furner have strengthened some of the conclusions.

PROPOSED MAGNETIC AND ALLIED OBSERVATIONS DURING THE TOTAL SOLAR ECLIPSE OF SEPTEMBER 10, 1923.

By Louis A. Bauer and J. A. Fleming

Special magnetic and allied observations will be made at stations inside and outside the shadow belt of the total solar eclipse of September 10, 1923, by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, and by various co-operating magnetic observatories, institutions, and individuals. The distribution of the magnetic observatories within the limits of the eclipse and on both sides of the belt of totality is shown by the accompanying map taken from the American Ephemeris and Nautical Almanac for 1923 and on which the positions of these observatories have been indicated.

The observatories, either within or near the limits of the eclipse, are: North of the belt of totality, Sitka (Alaska), Meanook (Alberta), Tucson (Arizona), Agincourt (Ontario), Cheltenham (Maryland), and Vieques (Porto Rico); to the south of the belt of totality, Honolulu (Hawaii), Cuajimalpa (Mexico), and Huancayo (Peru); while just outside the limits of the eclipse, at beginning and ending, are Kakioka (Japan) and La Quiaca (Argentina). Of the observatories, that at Tucson is particularly well situated, being only about two hundred miles from the central path of the eclipse; the maximum obscuration at Tucson will be about ninety-two per cent. It is planned that the Department of Terrestrial Magnetism will have parties at two (possibly three) stations within the belt of totality to make magnetic and atmospheric-electric observations. The United States Coast and Geodetic Survey will have one special party for taking magnetic observations within the belt of totality in southern California and will have special observations carried out at its observatories.

At the Mt. Wilson Observatory of the Carnegie Institution of Washington the obscuration will amount to ninety-eight per cent. A special program of astronomical observations will be followed by a party from that observatory at some point in California within the belt of totality, and it is planned that one of the parties of the Department of Terrestrial Magnetism will also be located there, and that some magnetic and allied observations may be made at a mountain station, for example, Mt. Wilson.

The general scheme of work is as follows:

1. *Simultaneous magnetic observations* of any or all the elements according to the instruments at the observer's disposal, every

minute from September 10, 1923, $17^h\ 28^m$ to $24^h\ 02^m$ Greenwich civil mean time.

(To insure the highest degree of accuracy, the observer should begin work early enough to have everything in complete readiness in proper time. *Past experience has shown it to be essential that the same observer make the readings throughout the entire interval.* If possible, similar observations for the same interval of time as on September 10 should be made on September 9 and 11.)

2. At *magnetic observatories* all necessary precautions should be taken to insure that the self-recording instruments will be in good operation not only during the proposed interval, but also for some time before and after, and eye-readings should be taken in addition wherever it is possible and convenient. (*It is recommended that, in general, the magnetograph be run on the usual speed throughout the interval, and that, if a change in recording speed be made, every precaution possible be taken to guard against instrumental changes likely to affect the continuity of the base-line.*)

3. *Atmospheric-electric observations* are desirable to the fullest extent made possible by the available equipment and personnel. Observations of potential gradient are most easily provided for and most conveniently taken; in addition to these, observations (preferably for both signs) of either conductivity or ionic content are also very desirable. Full notes regarding cloud and wind conditions and, if possible, observations for both temperature and relative humidity should accompany the atmospheric-electric observations. These observations should cover the same interval as the magnetic observations. The value of the observations on the day of the eclipse will be greatly increased if similar observations can be made during the same time of day on two or three days before and after the eclipse.

4. *Meteorological observations* in accordance with the observer's equipment should be made at convenient periods (as short as possible) through the interval. It is suggested that, at least, temperature be read every fifth minute (directly after the magnetic reading for that minute).

5. *Observers in the belt of totality* are requested to take the magnetic reading every 30 seconds during the interval, 10 minutes before to 10 minutes after the time of totality, and to read temperature also every 30 seconds, between the magnetic readings.

It is hoped that full reports will be forwarded as soon as possible for publication. Those interested are referred to the results of the observations made during the solar eclipse of May 29, 1919, which were published in the December, 1919, and in the June, September, and December, 1920, issues of *Terrestrial Magnetism and Atmospheric Electricity.* The observations and reports for 27 observatories (including a temporary magnetic observatory at Christmas Island) and 10 field stations where special programs were followed during the eclipse of September 21, 1923, are now being compiled. It is hoped that the publication of these reports may be begun soon.

General Circumstances of the Total Solar Eclipse of September 10, 1923.

Phase	Greenwich civil mean time				Longitude from Greenwich		Latitude		
		d	h	m	°	′	°	′	
Eclipse begins	Sep.	10	18	14.3	171	51 E	36	51	N
Central eclipse begins		10	19	16.9	154	18 E	48	16	N
Central eclipse at local apparent noon.		10	20	30.2	128	16W	37	58	N
Central eclipse ends		10	22	17.4	63	51W	13	43	N
Eclipse ends		10	23	19.9	80	31W	2	15	N

Additional details regarding this eclipse and meteorological and living conditions at places within the belt of totality may be obtained from the following references:

Gallo, J. El eclipse total de Sol del 10 de Septiembre de 1923. Mem. Soc. Antonio Alzate, Mexico, v. 37, No. 3, Aug. 1920 (189-192 with pl.).

Gallo, J. The total eclipse of September 10, 1923. Pop. Astr., Northfield, Minn., v. 27, No. 3, March 1919 (133-135).

Total eclipse of September 10, 1923. Pop. Astr., Northfield, Minn., v. 31, No. 1, January 1923 (42).

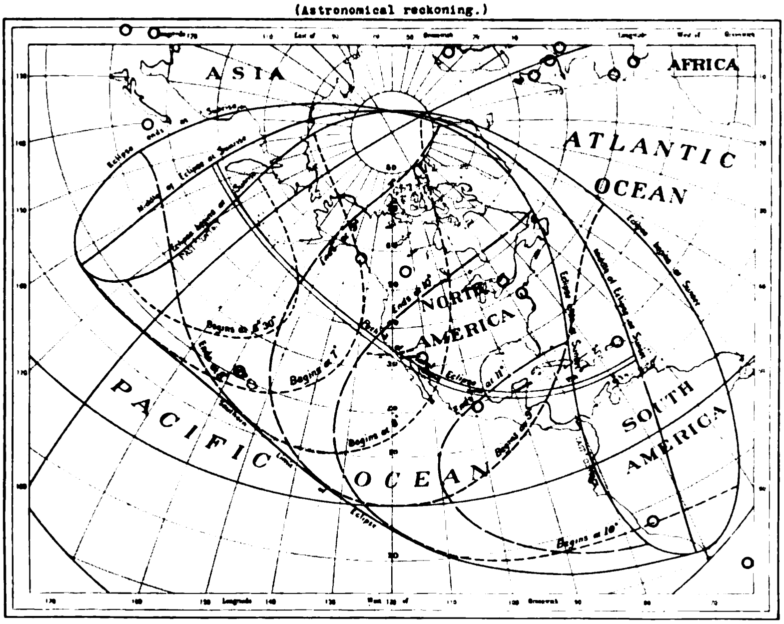
Abbot, C. G. The solar eclipse of September 10, 1923 (information regarding conditions at Ensenada). Science, New York, N. Y., N. S., v. 57, No. 1473, March 23, 1923 (353-354).

Campbell, W. W. Report of the Eclipse Committee March 1923 (29th meeting of the American Astronomical Society). Pop. Astr., Northfield, Minn., v. 31, No. 4, April 1923 (260-266).

Rigge, Wm. F. Eclipse of the Sun, 1923, September 10, as visible in the United States. Pop. Astr., Northfield, Minn., v. 31, No. 5, May 1923 (339-341).

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON.

TOTAL ECLIPSE OF SEPTEMBER 10, 1923
(Astronomical reckoning.)



Magnetic Observatories are indicated by circles (O)

Note: The hours of beginning and ending are expressed in Greenwich Mean Time.

PROVISIONAL SUN-SPOT NUMBERS FOR OCTOBER 1922 TO MARCH 1923.

By A. Wolfer.

Table 1.—October to December 1922.

	1922		
Day	October	November	December
1	10	12	..
2	8	..	27
3	8	..	25
4	9	0	23
5	0	7	23
6	0	8	22
7	..	15	..
8	..	9	15
9	..	..	18
10	9?	12	17
11	..	11	..
12	18	..	0
13	8	..	..
14	7	..	0
15	..	7	..
16	..	7	0
17	10	7	0
18	..	..	..
19	..	7	0
20	..	..	0
21	11	11	..
22	..	..	..
23	..	0	..
24	..	..	..
25	..	0	..
26	..	0	40
27	..	0	44
28	..	..	47
29	..	..	..
30	7	8	..
31	9		35
Mean	8.1	6.7	18.7

Mean for year 1922, R = 14.7

Table 2.—January to March 1923.

	1923		
Day	January	February	March
1	28	..	0
2	32	0	0
3	10	0	0
4	..	..	0
5	..	0	0
6	0	..	0
7	0	7	..
8	..	0	0
9	0	0	0
10	0	0	0
11	0	..	..
12	0	..	..
13	0	9	0
14	0	8	..
15	0	..	..
16	..	7	7
17	..	..	0
18	0	0	0
19	0	0	0
20	..	0	7
21	7	0	0
22	7	0	12
23	8	0	10
24	0	0	7
25	..	..	8
26	..	0	7
27	..	0	0
28	8	0	0
29	..		13
30	..		15
31	..		16
Mean	5.3	1.6	4.0

Sternwarte, Zürich.

THE CRITERION OF MAGNETIC DISTURBANCE.

By Charles Chree.

1. A primary desideratum is to arrive at a clear idea of exactly what it is we want to measure. If our object is simply to discriminate between the days of a single month, with a view to selecting for special purposes the five quietest or five most disturbed days of the month, it is very doubtful whether the existing scheme of international "character" figures can be improved on. Its simplicity and the small amount of labor it entails are great recommendations. The disadvantages it seems to me to possess are: 1. The significance of any particular "character" figure, *e. g.*, 1.5, is variable: it connotes decidedly less disturbance in a quiet than in a disturbed year. Also, while the mean "character" figure for the year does to a certain extent wax and wane with disturbance, the variation seems to me inadequate: 2. The assigning of "character figures" at an individual station is largely a psychological process, depending on the temperament and knowledge of the judge. The standards in use at different stations at the same time are widely different, and the standard in use at any particular station may vary largely from time to time. The "character" figures supplied by any two stations do not suffice for a satisfactory intercomparison of the stations, and if we wish to compare one year or season with another the international "character" figures leave a great deal to be desired.

2. The first serious attempt to arrive at an exact numerical measure is due to Bidlingmaier. His point of departure was the formula for the energy of a magnetic field

$$\frac{1}{8\pi}\iiint (X^2+Y^2+Z^2)\,dx\,dy\,dz,$$

where X, Y, Z denote the three rectangular components of force. If $\triangle X$, $\triangle Y$, $\triangle Z$ denote (algebraic) departures from "normal" values X_0, Y_0, Z_0, we may replace the above integral by

$$I_0+I_1+I_2,$$

where

$$I_0=\iiint i_0\,dx\,dy\,dz, \text{ with } i_0=(X_0^2+Y_0^2+Z_0^2)/8\pi$$

$$I_1=\iiint i_1\,dx\,dy\,dz, \text{ with } i_1=(X_0\triangle X+Y_0\triangle Y+Z_0\triangle Z)/4\pi$$

$$I_2=\iiint i_2\,dx\,dy\,dz, \text{ with } i_2=(\triangle X^2+\triangle Y^2+\triangle Z^2)/8\pi.$$

To obtain the total energy, the integration must extend throughout the whole magnetic field, and there is not necessarily any simple

relation between the result of this volume integration and the result obtained from a surface integration of i_0, i_1, and i_2 over the Earth's surface. For the present purpose I_0 and i_0 as constants may be neglected. Bidlingmaier defined his "activity" as the mean value of i_2 for the day at the station concerned. To obtain a fair mean vlaue of i_2 over the Earth's surface, we would require data from a very large number of well-distributed stations. As no such distribution of stations exists, we cannot really get a fair equivalent to surface integration of i_2; and, even if we did, the result would not stand in any known relationship to the corresponding mean value of I_2. We must, in short, regard Bidlingmaier's use of i_2 as based on analogy. His "activity" waxes and wanes with disturbance, and so may be regarded in a sense as measuring disturbance. But it includes not merely disturbance, but also the regular diurnal variation, and it does not—like the present international "character" figure—vanish for the quietest of days.

3. It is hardly likely that Bidlingmaier overlooked the existence of I_1. He may have supposed that the mean value of i_1 for a day over the whole Earth was likely to vanish, the signs of $\triangle X$, $\triangle Y$, and $\triangle Z$ being now plus now minus; or he may simply have recognized that i_1 is too uncertain a quantity for practical use. The suitability of Bidlingmaier's "activity" as a measure of disturbance was considered by several magneticians, myself included. If the existence of I_1 had escaped my notice—which was not the case—my attention would have been called to it by some remarks on its omission by Sir J. J. Thomson on an occasion when a paper containing some "activity" results for British stations was read before the Royal Society. It seemed to me that whatever importance I_1 might possess in an actual calculation of the energy of the Earth's field, i_1 was a quite unsuitable quantity for use in estimating the disturbance shown by magnetic curves at individual stations. The sign of i_1 would vary as the elements rose above or fell below their normals. Take, for simplicity, the case of a station on the agonal line and in the magnetic equator. Taking X to the north, we have

$$Y_0=Z_0=0, \quad X_0=H \text{ (horizontal force)}.$$

The amplitude and sign of i_1 would depend solely on the amplitude and direction of the change in H. Suppose a magnetic storm of long duration to have a large S. C. (sudden commencement), with a "crest" extending over the evening hours of the first day of disturbance. Suppose the second day to present a succession of large oscillations, now on the plus now on the minus side of the normal, finishing up with the depression customary in low and mean latitudes at the end of large storms. Suppose the third day of disturbance to commence with a big depression, but to be free from any large oscillations. Employing $\bar{i}_1$ to represent the (algebraic) mean value of i_1 for the day, we should have $\bar{i}_1$ large and positive for the first day, numerically large but negative for the third day,

and possibly zero for the intermediate day, which to the ordinary man would seem much the most disturbed day of the three.

A difficult question would at once arise as to how to arrive at the "normal" values for the day. The secular change would have to be allowed for. Its mean value for the year would be unknown until the year's end, and the absolute values of the elements might possess an annual inequality. Then should our normals be derived from all days or from quiet-day results? In ordinary latitudes quiet-day monthly means of H usually exceed all-day monthly means, the excess being of the order of 3γ. If we suppose $X = 30000\gamma$, and $\triangle X = 3\gamma$, we get $X \triangle X = (300\gamma)^2$. Obviously, in low magnetic latitudes, in quiet days, the uncertainty from this cause in the value of i_1 would be all-important. Another consideration is that for the Earth as a whole, the mean value of i_1 will largely depend on the phenomena in high magnetic latitudes, where, at present, observatories hardly exist. For just as the value of i_1 in low magnetic latitudes is mainly dependent on $H \triangle H$, so in high latitudes it is mainly dependent on $Z \triangle Z$, supposing z vertical. Large as H is near the magnetic equator, Z is twice as large near the poles. Also, while changes in Z are usually small compared with those in H in low magnetic latitudes, this is less the case as the latitude increases. The changes in Z observed in high latitudes, in moderately disturbed days are in fact usually larger than the corresponding changes in H observed in low latitudes. Thus the mean value of i_1 over the Earth's surface for any given day is likely to be largely influenced by the contributions from $Z \triangle Z$ in high latitudes.

4. The first serious attempt known to me to employ the integral to calculate the true energy of a magnetic storm is due to Prof. S. Chapman, who recognized the existence of both I_1 and I_2. Chapman[1] described I_2 as the "self-energy" integral, and I_1 as the "joint-energy" integral. I_2, he says, "is equal to what would be the energy of the disturbance field if existing by itself, in the absence of the permanent field." While I_1, he says, "has usually been neglected, on the ground that the permanent and disturbance fields being independent, on the average there will be no net gain or loss due to their superposition. This is true as regards the harmonic components corresponding to local irregular fluctuations of magnetic force during the storm, and also as regards what I (Chapman) have elsewhere termed the 'local time variations,' which mainly represent a longitudinal inequality in the world-wide diminution of horizontal magnetic intensity. But it is not true of the harmonic component corresponding to the latter variation, averaged along each circle of latitude, and the term hence arising in the joint-energy integral proves to be the most important part of the whole excess energy."

As the precise way in which this "excess energy" arises from I_1 is of interest in the present connection, I will quote what Chapman says on the subject in his §14, premising by way of explanation that

[1] R. A. S. *Notices*, vol. 79 (1919), p. 70.

Chapman supposes the ultimate cause of the storm to be an overhead "current sheet." He proceeds: "The sign of the joint-energy integral is positive, representing an increase in the energy of the magnetic field. This may seem curious, considering that the most notable effect of magnetic storms is to diminish the horizontal magnetic intensity. The above value of $\delta\Omega$ (potential), however, corresponds to an *increase* in the magnetic field within the Earth and outside the atmospheric current-sheet. Only between the two is there anywhere a diminution of field intensity, and that only near the equator; for while the horizontal force is diminished, the vertical force is increased, so that near the poles the energy of the field is increased. As has been seen in §13, the two effects just balance, and the total energy of the field between the Earth's surface and the current sheet is unaffected."

What this all means is that, taking a certain hypothetical storm, Chapman found I_2/I_1 small. The value of I_1 arose not from oscillatory movements, but from the depression in H, customary in the latter part of magnetic storms, and the corresponding increase usually observed in the vertical force. The volume integral had to be taken, first throughout the interior of the Earth, second throughout space exterior to the hypothetical overhead current sheet causing the storm, and third for the space between the Earth and the current sheet. The last space is the only one of which we have direct cognizance, and its contribution to the value of I_1 was exactly zero.

To reach any numerical results at all, heroic hypotheses were indispensable, and the probability attaching to the hypotheses which Chapman actually did make will probably be very differently assessed by different people. But, however this may be, his investigations at least show how risky it would be to draw any inference as to the relationship between the real energy integral I_1 and the surface integral of i_1 over the Earth's surface.

I am uncertain whether Chapman relied on theory or on observation for the truth of the statement that a magnetic storm normally raises the vertical force while depressing H. The regions in which the truth of the statement is of primary importance in the present connection are the high magnetic latitudes, respecting which our information has hitherto been very scanty. But, as a matter of fact, the statement does seem in general accordance with the phenomena observed in the Antarctic in 1911-13 by the Scott and Australasian expeditions.

5. Somewhat later Dr. Bauer,[1] who was apparently unaware of Chapman's work, gave reasons for believing that Bidlingmaier's neglect of I_1 was unjustifiable. In Dr. Bauer's formula (6), §20, *l. c.* p. 55, there appears $XdX+YdY+\frac{1}{4}ZdZ$ in place of $X_0\triangle X+Y_0\triangle Y+Z_0\triangle Z$ in i_1. There is no real difference, as Dr. Bauer uses d instead of my $\triangle$ to denote departure from the standard value, except as regards the $\frac{1}{4}$ appearing in the Z-term. Dr. Bauer is here

[1] *Terr. Mag.*, vol. XXVI, pp. 53 *et seq.*

dealing with a special hypothesis, not with the complete Earth's field, and he regards $(dX)^2$, etc., apparently as negligible. But in his next section, 21, his equation at the top of page 56—assuming the index 2 outside the bracket in the expression $(Z_1^2-Z_0^2)^2$ a printer's error—would clearly, if expanded in full, agree with Chapman's form of i_1. Even if the factor ¼ were correct. I should be unable to accept Dr. Bauer's conclusion (*l. c.* section 23, p. 57). "Fortunately it turns out that, excepting for stations of high magnetic latitude, the dZ-term is, in general, negligible in comparison to the combined quantity $XdX+YdY=HdH$." Here dX, dY, and dH represent departures from the mean values of the horizontal components, X and Y, and the horizontal intensity, H, but in the numerical illustrations thus far given by Dr. Bauer, he uses for dH the daily range of H.

6. Let us now consider the practical side more closely. None of the new criteria considered recently by Dr. van Dijk[1] or Dr. Bauer[2] can really supply a direct measure of disturbance alone, as customarily understood. All the criteria give finite values for any day, however quiet. On the quietest of days, in years of sunspot minimum, the range shows no approach to zero. Any criterion based on the daily range which is intended to supply a zero value on an ideally quiet day should be a function of $R-R_0$, where R is the range for the particular day and R_0 that for the ideal quiet day. Now the range on the quietest days experienced is continually varying with the season of the year, and with the sunspot frequency. We should thus really require a constantly varying R_0. It is difficult to see how this could be assigned, even at stations with many years of accumulated records. At a new station the difficulty would seem insuperable.

An obvious objection to any criterion based solely on the daily range—whether the absolute range, or a range from mean hourly values, whether the range of a single element or a combination of ranges from several elements—is that a single large oscillation limited to part of one hour may supply both the maximum and minimum for the day, and, so far as the disturbance criterion is concerned, it is immaterial whether the remainder of the day is absolutely quiet or continuously and highly disturbed.

In this respect Bidlingmaier's "activity" is undoubtedly superior, and the same is true of a criterion applied by Dr. Crichton Mitchell involving the sum of the squares of the absolute hourly ranges of the three components. The objection to both these measures is the amount of labor entailed. This objection has, I think, been considered absolutely fatal by all who have considered Bidlingmaier's "activity" critically. It was the recognition of this that led me to suggest $C(R_1^2+R_2^2+R_3^2)$, where C is any convenient constant, and R_1, R_2, R_3 the absolute daily ranges for three rectangular components. The claim made for this criterion was not that it possesses an exact ascertainable physical meaning, but simply that

[1]K. *Ned. Met. Inst.* No. 102, 1922. [2]*Terr. Mag.*, vol. XXVII, p. 31.

it is a quantity of the same nature and order as Bidlingmaier's "activity," showing a fair general parallelism from day to day with that "activity," but involving a comparatively trifling amount of labor for its evaluation. It would undoubtedly wax and wane with disturbance, and give a measure independent of the eccentricities of the human element. I really entertained a doubt whether $R_1^2+R_2^2+R_3^2$ or $(R_1^2+R_2^2+R_3^2)^{1/2}$ would be the better criterion. The latter quantity would be free from what Dr. Bauer seemingly considers a defect in the former, viz., that the contribution from a single day may be a considerable fraction of the contribution from the whole month. To me there seems no obvious reason why the contribution from a single day of exceptional disturbance should not equal the sum of the contributions from many days of little disturbance. This is exactly what happens at times with some of the meteorological elements. The rainfall from a single day may exceed the rainfall from the remaining days of the month. The travel of the wind in twenty-four hours of a great gale may exceed that of twenty calm days. The point I think is really this: Does doubling the absolute range represent on the average merely a twofold disturbance? If such be the case, then a criterion having the order of the first power of the range is desirable. If, however, it appears on consideration that doubling the range answers more nearly to quadrupling the disturbance, then the second power of the range is desirable in the criterion. This point might, perhaps with advantage, be referred to a jury of magneticians.

The absolute daily range of a single element—whether H or D, N or W—forms a very fair criterion for discriminating between the quiet and disturbed days of the month. I speak from considerable experience, having employed H and D ranges separately for investigations covering long periods of years. In low latitudes H is a much more disturbed element than D, and if only one element is to be used, H in these latitudes would be much the best. But in mean latitudes the disturbance in D, when translated into force, is quite comparable with that in H; and it not infrequently happens that the disturbance shown by the one element—D one day, H another—is markedly in excess of that shown by the other. Thus the relative positions of the days of a month arranged in order of disturbance would depend on which element supplied the criterion. Again there are occasions, increasing in frequency with the magnetic latitude, when the vertical force range rivals that of the horizontal components. These considerations suggest the adoption of a criterion involving the ranges of all three elements.

7. To avoid throwing excessive labor on the central station, I would suggest that the data sent to it from each co-operating station should be the mean value of the criterion calculated from all days of the month, with the ratios borne to this mean by the daily values. For instance, if $R_1^2+R_2^2+R_3^2$ were the criterion, the monthly data sent up would consist of $C(\overline{R_1^2+R_2^2+R_3^2})$[1]—with C

[1]Here $\overline{R_1^2}+\overline{R_2^2}+\overline{R_3^2}$ signifies the mean value of $R_1^2+R_2^2+R_3^2$. The distinction between the mean square and the square of the mean must be remembered.

any convenient constant agreed on—the arithmetic mean value for the month, and the daily values of the ratio $(R_1^2+R_2^2+R_3^2)/(\bar{R}_1^2+\bar{R}_2^2+\bar{R}_3^2)$. If the criterion, on the other hand, were the first-power daily ranges uncombined, the data sent up might be the separate arithmetic means $\bar{R}_1$, $\bar{R}_2$, and $\bar{R}_3$, and the daily values of $\frac{1}{3}[(R_1/\bar{R}_1)+(R_2/\bar{R}_2)+(R_3/\bar{R}_3)]$. In any case it would probably suffice to give these single station daily ratios to 0.1. The central station could then find the arithmetic mean of all the daily ratios assigned to a single day, and assign this as the international "character" figure for the day. In this way co-operating stations would have practically equal weight, as at present, in the final estimate. These final figures could serve for discriminating between the days of a single month, just as the present international "character" figures do; while the mean monthly values of the criterion would serve for the intercomparison of different years or seasons.

If a criterion having the dimensions of the first power of a range is deemed best, my own view is that $(R_1^2+R_2^2+R_3^2)^{\frac{1}{2}}$ would utilize all three ranges in a more satisfactory way than $R_1+R_2+R_3$. For a daily "character" figure $[(R_1^2+R_2^2+R_3^2)/(\bar{R}_1^2+\bar{R}_2^2+\bar{R}_3^2)]^{\frac{1}{2}}$ or $\frac{1}{3}[(R_1/\bar{R}_1)+(R_2/\bar{R}_2)+(R_3/\bar{R}_3)]$ seems to me distinctly preferable from a physical point of view to $(R_1+R_2+R_3)/(\bar{R}_1+\bar{R}_2+\bar{R}_3)$.

So far as measurement of the curves is concerned, $R_1^2+R_2^2+R_3^2$ implies no more labor than $R_1+R_2+R_3$. It implies some more arithmetic, but only very little if Crelle's table of squares is used. As a daily "character" figure $\frac{1}{3}[(R_1/\bar{R}_1)+(R_2/\bar{R}_2)+(R_3/\bar{R}_3)]$ has a certain advantage, inasmuch as it is independent of the scale values, assuming these constant across the sheet, and so is unaffected by any errors in scale values. Scale value errors would, however, effect the monthly mean values as much in this case as in any other.

The use of ranges from mean hourly values ascribed by Dr. Bauer to Prof. Ad. Schmidt would give increased importance to the regular as compared with the irregular movements of the day. This would seem a step in the wrong direction, if it is disturbance that we specially wish to measure.

It is obviously desirable that all stations participating in an international scheme should use the same criterion. There are some, possibly a good many, stations whose vertical force records are less reliable than those of *D* and *H*, and it is possible that the inclusion of all three elements in the criterion might lead to the exclusion of several stations. Again, it is possible to assign "character" figures 0, 1, 2 at stations where disturbances due to electric trains and trams would prevent reliable measures of absolute ranges. Thus there are undoubtedly a certain number of stations, participating in the present international scheme, which would be likely to drop out if exact measurements became necessary of the absolute ranges of three elements.

Another consideration is that loss of trace would become much

more serious. At present, so far as the "character" figure is concerned, it is immaterial whether a very large magnetic storm is completely recorded or not at a particular station. With half the full range shown, the ordinary judge would assign a 2, and more he cannot give. But when the criterion depends on the absolute size of a range it is different. The procedure to be followed in the case of loss of trace would call for careful consideration.

The best policy—at least for a time—would probably be to continue the existing scheme at all stations, and get a limited number of representative well-equipped stations to obtain in addition results from the new scheme, whatever that might be.

8. A few comments on the comparative figures given by Dr. Bauer,[1] as obtained from Dr. van Dijk's publication,[2] may be of service. All the magnetic criteria applied in columns 2 ($\bar{B}i$) to 6 give results which increase with the range, irrespective of the presence of disturbance. The regular diurnal variation is naturally much smaller at midwinter than in summer. This, no doubt, tended, as De Bilt is a northern station, to depress the values in January, February, November, and December. A really fair intercomparison of the several months of the year would require the southern and northern hemispheres to be equally represented. In the case of the present "character" figures there is some representation of the southern hemisphere, also the majority of the co-operating stations in the northern hemisphere are in lower latitudes than De Bilt, where the difference between summer and winter is less. This is presumably accountable, at least in part, for the dissimilarity between the results in the column headed *Me* and those in columns 2 to 6. As regards the solar data, the correlation between the mean sunspot area or number for the entire year and the corresponding range of the mean diurnal magnetic inequality is close, the relation being linear of the form $R=a+bS$, where S is the sunspot area or number and a, b constants. If we consider the diurnal inequalities of the twelve months separately for a long series of years, we also obtain fair results from a linear relation of the above type, but the values of a, b and b/a vary throughout the year. If, however, we take the absolute daily magnetic range, the correlation with sunspots is not very close, even when we consider complete years. Years of sunspot maximum are by no means necessarily years of maximum absolute magnetic range. The correlation between magnetic disturbance or absolute ranges and the sunspot measure for individual days is far from close. Thus I do not think we should look to solar phenomena for guidance in selecting a criterion for the magnetic disturbance of individual days.

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[1] *Terr. Mag.*, vol. XXVII, p. 32.
[2] *Ned. Met. Inst.*, No. 102, Utrecht, 1922.

REGARDING MEASURES OF MAGNETIC CHARACTERIZATION OF DAYS.

By Louis A. Bauer.

1. Experience has shown that the Bidlingmaier "activity" measure for the magnetic characterization of days entails too much labor to be successfully put into general practice. Accordingly, Chree,[1] Hazard,[2] Adolf Schmidt,[3] Bauer,[4] and van Dijk,[5] have been led to suggest other methods of procedure for obtaining measures of magnetic activity. It is also being recognized more and more that the so-called international magnetic "character" numbers, issued for quarterly periods by the De Bilt Observatory in behalf of the Commission on Terrestrial Magnetism and Atmospheric Electricity of the International Meteorological Committee, do not serve all the purposes desired. The time therefore has come when it would seem advantageous to omit further discussion of past methods and give serious attention to finding some comparatively simple method for the magnetic characterization of days, the adoption of which will not greatly add to the work of the usual observatory personnel.

2. Too much must not be expected of any measure of magnetic activity, as it is quite likely that no one measure will suffice for *all* investigational purposes. Furthermore, it should not be overlooked that the precise numerical value of any measure adopted will depend upon the geographic region embraced by the contributing observatories. This is true, for example, in the case of the magnetic "character" numbers. In the last list (October-December, 1922), just come to hand, nearly half of the 42 contributing observatories are in Europe and only about one-sixth, in the South Hemisphere. The indiscriminate mean of the "character" numbers from all observatories accordingly very largely depends upon the European "character" numbers.

3. The question arises whether a more satisfactory international "character" number might not be obtained by a suitable system of weighting of stations so as to prevent overweighting of any particular region. Another method of procedure would be to obtain the mean character number from a number of carefully-selected stations as uniformly distributed over the globe as conditions per-

[1] *Terr. Mag.*, vol. 22 (1917), 57-83; see particularly this issue of the Journal, pp. 33-40.
[2] *Terr. Mag.*, vol. 22 (1917), 84-86.
[3] *Terr. Mag.*, vol. 25 (1920), 123-138.
[4] *Terr. Mag.*, vol. 26 (1921), 53-62, and vol. 27 (1922), 31-34.
[5] *K. Ned. Met. Inst.*, No. 102, Utrecht, 1922; see also *Terr. Mag.*, vol. 27 (1922), 31-34.

mit. The latter procedure would be more readily possible if the measure of magnetic activity were a perfectly determinable quantity and did not depend upon individual judgment, as do the "character" numbers. There have been cases when the mean "character" numbers given for the same month by the various observatories in Europe, and sometimes in the same country, showed as large a range amongst themselves as exhibited by the mean international "character" numbers during the entire sun-spot cycle

4. Another matter for careful consideration is whether the "five internationally magnetically-calm days per month" really are most representative of "normal" conditions. "Quiet" days not infrequently are affected by a peculiar type of disturbance of their own. It has thus happened at times that when quiet days were selected as representative "normal" days, the resulting magnetic measure came out negative, instead of positive, as was expected. Indeed, it would appear well worth while considering whether a larger number of the lesser disturbed days per month, of magnetic "character" 0 and 1, as, for example, 10, as is done by the United States Coast and Geodetic Survey, might not, in general, represent normal or average magnetic conditions of the Earth more satisfactorily. The days per month selected for international data would then apply to more of the observing stations than do the present zero "character" days alone.

5. In the selection of the desired magnetic measure it would seem that not too much emphasis should be laid upon the question whether the measure will also be wholly suitable for occasional arctic and antarctic stations, or for high magnetic latitude stations. These are isolated cases that may well be put in a class of their own, if experience so finds necessary. If a satisfactory simple measure is found for the greater portion of the Earth, let us say 75 per cent, as approximately represented by the present distribution of magnetic observatories, we may well rest content.

6. Other than the "character" numbers, I do not know of any measure which has been tested for the greater part of the Earth except the one tentatively proposed by me, namely, ϵHR_H, where ϵ is a numerical constant, H, the absolute value and R_H, the range of the horizontal intensity at the observing station.[6] My experience would indicate that a linear measure, dependent upon the variations of so sensitive an element to change, as is H usually, may be brought into a form which suffices for most purposes. Instead of the range, R_H, we might use, for example, the average departure Δ, of the H hourly values from the daily mean. It is hoped, however, that such a refinement, for general purposes, will not be necessary. Furthermore, the H-residuals from a daily or monthly mean are usually sufficiently accidental in their distribution so that Δ and

[6]See footnote references (4). The formula was tentatively developed from the expression of the energy for a simple type of magnetic field; the energy function was used by the author first in his magnetic investigations published in *Terr. Mag.*, vol. 8 (1903), 97-111, or prior to the use of the function by Bidlingmaier and Chapman for their particular objects. The specimen computations given in *Terr. Mag.*, vol. 26 (1921), 59-61, only represent a portion of the tests carried out.

R_H may be regarded as approximately proportional to one another, as would be required by the theory of probability. Hence, R_H is given first preference, especially since to obtain $\triangle$ requires more computation.

7. Instead of ϵHR_H, we might find ϵHR_D, where R_D is the declination range, sufficiently suitable for general requirements. The advantage here would be that R_D is independent of any temperature correction, whereas, R_H could not be derived accurately, if necessary to do so, until the extreme values of H had been reduced to standard temperature; for many observatories, however, the daily temperature range inside the magnetograph room is so small that the value of R_H, obtained from the directly scaled extreme values of H would be, in general, sufficiently accurate.

8. A question to be decided also is whether to use the absolute, or actual, ranges of the selected magnetic element, or to use ranges as obtained from the momentary hourly values, or from the 60-minute hourly values. If more or less smoothed ranges are used it is much easier to find a generally satisfactory magnetic measure than when absolute ranges are used. The settlement of this question, as well as what magnetic element or elements to use for the magnetic measure, will depend upon the number of co-operating magnetic observatories, which may be found to follow essentially the same methods of registration and of evaluation of the magnetic curves.

9. A satisfactory measure of magnetic activity should also, if possible, take into account the disturbances from day to day in the daily mean values of the recorded magnetic elements, aside from the slowly progressive secular changes. Some consideration is likewise being given to this question.

10. While it may be found necessary, for certain special investigations, to use a measure of magnetic activity of the quadratic type, such as latterly suggested by Crichton Mitchell and Chree, I am of the opinion that the additional labor involved will not, in general, be found justified. It is a great convenience, especially when one wishes to compute magnetic measures for past years, to be able to obtain the mean monthly measure, without computing the measure for each day of the month, as would be necessary for a quadratic formula. Then again the more magnetic elements taken into consideration in the formula, the more difficult it will be to find a sufficient number of strictly comparable stations over the Earth. A further objection to such a proposal, as suggested by Chree, is that it does not yield a continuous set of figures, as is the case with the magnetic "character" numbers. Chree would obtain one set of measures showing the variation in magnetic activity for each day in any particular month. Next he would obtain a different set of measures exhibiting the change in magnetic activity from month to month, and finally another set for the magnetic activity change from year to year.

11. I am inclined to agree with Dr. Chree that "the best policy —at least for a time—would probably be to continue the existing scheme (magnetic character numbers) at all stations, and get a limited number of representative well-equipped stations to obtain in addition results from the new scheme whatever that might be." In order to try out thoroughly the suggestions made in this preliminary communication, a limited number of comparable observatories will be asked to send to the Department of Terrestrial Magnetism certain data, the supplying of which will entail minimum time and labor. It is hoped that Dr. Chree will also find it possible to make world tests of his proposals.

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON.

ERDMAGNETISCHE STÖRUNGEN UND SONNENTÄTIGKEIT.

VON G. ANGENHEISTER.

In einer früheren Mitteilung (*Terr. Mag.*, 1922, S. 57[1] und 1921, S. 116) habe ich zu zeigen versucht, was auch Ad. Schmidt schon früher ausgesprochen hat, dass man zwei verschiedene Perioden in der magnetischen Aktivität wiederfindet: eine 27tägige, die allgemein, sowohl für die ruhigsten wie die gestörten Tage, gilt, aber nur wenige Periodenlängen hindurch anhält; ferner zeigen die Daten der *grossen* magnetischen Störungen, dass sie sich nach Zwischenzeiten, die ganze Vielfache von 30 Tagen sind, zu wiederholen pflegen. Die kurzlebige 27tägige Periode ist wohl veranlasst durch Vorgänge, die ihren Ursprung im Flecken- und Fackelniveau der Sonne haben und an der Rotation dieses Niveaus teilnehmen. Für die in Frage kommenden niederen Sonnenbreiten sind solche Umlaufzeiten von ungefähr 27 Tagen beobachtet worden. Die warscheinlich über eine grössere Anzahl Jahre kohärente Periode von 30 Tagen liess dagegen vermuten, dass die Störungsquellen der *grossen* Störungen nicht in den obersten (in etwa 27 Tagen rotierenden), sondern in tieferen, unbeweglicheren Sonnenschichten zu suchen seien, die nach der Beobachtung auch langsamer rotieren. Wohl nur in einer solchen festeren Schicht kann sich eine Störungsquelle für lange in einer unveränderten Lage erhalten. Ich habe selbst darauf hingewiesen (*Terr. Mag.*, 1922, S. 76), dass man dann aber vermuten müsste, dass der 27, 54, 81ste Tag vor einer *grossen* Störung ungestört sei. Die Beobachtungen zeigen aber oft, dass diese Tage gestört sind, dass die grossen Störungen also in einen 27tägigen Cyclus eingereiht sind. Ich habe auf ein Beispiel hierfür hingewiesen (*Terr. Mag.*, 1922, S. 76 u. *Serie* I, S. 71). Auch Ch. Chree, zeigt in seiner Mitteilung (*Terr. Mag.*, 1922, S. 123), dass diesen grossen Störungen oftmals am 27, 54sten etc. gestörten Tage vom Charakter 1.2 bis 1.7 vorausgehen, und glaubt, deswegen könne kein grosser Unterschied im Entstehungsort der grossen und kleinen Störungen bestehen. Gewiss liegt hier eine Schwierigkeit.

Ad. Schmidt hat die 12 grössten in Potsdam aufgezeichneten Störungen von 1892-1921 in einer Tabelle zusammengestellt und daran die Existenz einer 29.97tägigen Periode nachgeprüft. (*Astr. Nachr.* B. 214, S. 411.) Für die Jahre 1906 bis 1921 liegen nun für jeden Tag die internationalen Charakterzahlen vor. Für die 7 letzten Störungen, No. 6 bis 12 der erwähnten Tabelle, die in diesen Zeitraum fallen, habe ich die Charakterzahlen für die jeder Störung vorangehenden Tage zusammengestellt. Die grösste Charakterzahl C der Zeit vom 40sten bis 20sten Tage, die der Hauptstörung vorangeht, ist in der Tabelle 2, nebst Datum, als "Vorstörung" angegeben; ferner ist die Anzahl N der Tage zwischen der Haupt- und Vorstörung und die für Potsdam geltende Intensität der Hauptstörung $\triangle = \triangle X + \triangle Y + \triangle Z$ in Gamma angegeben. Die Tabelle enthält alle Störungen von 1892-1921, deren $\triangle$ in Potsdam grösser als 1,000 Gamma war. No. 2 und 3 der Tabelle lassen sich auch als zusammengehörig auffassen. Diese Zusammenstellung zeigt, dass vor 8

[1] Diese Arbeit wurde Herbst 1920 der Gesellschaft d. Wissenschaft. zu Göttingen vorgelegt.

grossen Störungen 5 mal der 29. bis 31. vorangehende Tag gestört ist, und 3 mal der 25. bis 27. vorangehende Tag.

Bei der besonders grossen Störung vom Mai 1921 sind mehrere Tage hintereinander gestört: 12.-21. Mai. Die zugehörigen Charakter zahlen sind: 1.4-1.9-2.0-2.0-2.0-1.6-0.9-1.6-1.8-1.3 und ferner der vorangehende 18.-23. April (1.4-1.2-1.0-1.2-0.9-0.8) und der vorangehende 21.-27. März (1.4-1.3-0.3-0.9-1.3-1.2-1.3). Hier folgen sich also drei grössere Störungsareale in einem mittleren Abstand von 26½ und 26 Tagen. Ausserdem geht aber dem Anfang der Hauptstörung dem 13. Mai eine stärkere Störung voran (1.6) am 13. April, also 30 Tage vorher. Man hat also den Eindruck, dass ein ausgedehntes Störungsareal in der höheren Schicht (in 26½ Tagen rotierend) sich dem tiefer (in der in 30 Tagen rotierenden Schicht) liegenden gegenüber verschiebt, sich ihm nähert und Mitte Mai erreicht und dadurch die besonders grosse Störung vom 13. Mai zur Auslösung bringt. Die Coincidenz der Störungscentren in den beiden Schichten mag diese enorme Störungstätigkeit veranlasst haben.

Handelt es sich nun bei diesen besonders grossen Störungen, die in Form und Ausmass sich von den geringeren unterscheiden, wirklich um festliegende Störungscentren auf der Sonne? Es hat in der Tat den Anschein. Die 12 grössten Störungen von 1892-1902 der Tabelle von Ad. Schmidt lassen sich nämlich zum Teil als Wiederholung nach Ablauf der 11jährigen Periode auffassen. Die Differenzen der Eintrittszeiten von drei Paaren dieser Störungen, die sich einander zuordnen lassen, sind: für No. 1 und 5: 4277.2 Tage; für No. 5 und 9: 4246.8; für No. 8 und 12: 4248.0. Das Eintreten einer magnetischen Störung auf der Erde verlangt erstens eine Störungsursache auf der Sonne und zweitens eine bestimmte Lage dieser Störungsursache der Erde gegenüber. Diese günstige Lage mag sich nach Ablauf einer Sonnenrotation von 30 Tagen wiederholen. Wir haben also unter den 12 Störungen 5, die durch einen Zeitraum 4247 (beziehungsweise 4277 = 4247 + 30) Tage voneinander getrennt sind. Die übrigen ergeben weniger übereinstimmende Zwischenzeiten. Es lassen sich noch weitere Beispiele für eine Wiederholung nach ungefähr 4247 + 30 Tagen finden, z. B. die grösste Störung der Zeit vor Beginn der Tabelle 1 von 1882-1892, nämlich diejenige vom 1882, IV, 17.0, diese wiederholt sich nach 4279 = 4247 + 32 und 4275 = 4247 + 28 Tagen.

$\triangle$H bedeutet den Störungsbetrag in der Horizontal-Intensität.

TABELLE 1.

Datum	$\triangle$H	in	j = Julian Periode	$\triangle$j
	γ			
1882 IV 17.0	680	Zikawei	2408552	4279
1894 I 2.9	250	"	412831	
1905 IX 18	> 200	Samoa	417106	4275

Den Störungen vom 3. I. 1894 und 18. IX. 1905 kommt der Charakter 1.9 oder 2.0 zu. Doch besteht hier natürlich eine gewisse Willkür in der Auswahl dieser beiden Störungen. Diese Willkür bestand für die Tabelle der 12 Potsdamer Störungen nicht. Immerhin scheint es, dass sich bestimmte grosse Störungen nach 4247 oder 4277 Tagen wiederholen. Wenn die zusammengehörigen Störungen, No. 1, 5, 9, und No. 8 und 12, je ein festes Störungscentrum auf der Sonne besitzen und dieses in einer Schicht liegt, die in nahezu 30 Tagen rotiert, so werden in 4277 Tagen 143 Rotationen von 29.91 Tagen stattfinden. Der mittlere Abstand der beiden Störungsgruppen 1, 5, 9 und 8, 12 voneinander innerhalb einer solchen 29.91-tägigen Schicht beträgt dann 3 Tage. Sie fallen auf die folgenden Rotationstage: 28.-28.-27.; und 0.-1.

Sie könnten also sehr wohl einunddemselben grösseren Störungsareal auf der Sonne angehören. Es werden häufiger, als es zufällig sein könnte, grössere magnetische Störungen beobachtet, die einander nach 3-5 Tagen verhältnismässiger Ruhe folgen. Dafür spricht auch das Folgende. In der Tabelle von Ch. Chree (*Phil. Trans. Roy. Soc.* London, 1913, p. 261) sind die Störungscharaktere der Tage vor und nach der Störung eingetragen. Es zeigt sich dort, dass der vorangehende 27ste Tag, die Vorstörung, und in geringerem Masse der diametral gegenüberliegende 13 und 14te Tag stärker gestört sind als die benachbarten Tage. Ausserdem ist aber der 5te Tag vor der Störung und der 5te Tag vor und nach der Vorstörung (also der 22 und 32ste Tag vor der Störung) stärker gestört als die benachbarten Tage. Die magnetischen Ereignisse, deren Quellen mit einer höheren Sonnenschicht in 27 Tagen zu rotieren scheinen, haben offenbar bei aller Verschiedenheit im Einzelnen doch eine im Mittel konstante zeitliche Anordnung gegen einander, deren letzte Bedingtheit vielleicht in einer festen Lage der Störungsherde in grösseren unbeweglicheren Sonnentiefen zu suchen ist.

TABELLE 2.

No.	Datum			Julianische Periode 2400000+	△	Vorstörung, V		C	n in Tagen
1	1892	II	13.1	12141.6	>1800				
2	94	VII	20.1	13029.6	1580				
3	94	VIII	19.9	13060.4	1410	VII	20		31
4	98	IX	9.7	14542.2	>1150				
5	1903	X	31.3	16418.8	2860				
6	07	II	9.6	16716.1	1340	I	11	1.6	29
7	08	IX	11.9	18196.4	1520	VIII	12	1.6	30
8	09	IX	25.5	18575.0	3800	VIII	29	1.4	27
9	15	VI	17.1	20665.6	1300	V	17	1.3	31
10	19	VIII	11.3	22181.8	2720	VII	17	1.4	25
11	20	III	22.4	22405.9	1870	II	24	1.6	26
12	21	V	13.5	22823.0	>3000	IV	13	1.6	30

LETTERS TO EDITOR

EARTHQUAKE RECORDS, HUANCAYO MAGNETOGRAMS, SEPTEMBER 1922 TO APRIL 1923.[1]

There were records of two small earthquakes on the magnetograms of the Huancayo Magnetic Observatory, in Peru, on September 4 and November 22, 1922. Each one appears to have been due to a short, sharp local shock. On September 4 the effect in declination occurred at $12^h\ 07^m$ with maximum range of 0.7mm; in horizontal intensity at $12^h\ 07^m$, the maximum range not measurable owing to rapid change in *H*, and in vertical intensity at $12^h\ 09^m$ with maximum range of 0.4 mm. On November 22 the effect in declination occurred at $14^h\ 14^m$ with maximum amplitude of 1.0 mm, and in horizontal intensity at $14^h\ 14^m$, the effect being indistinct owing to rapid change in *H*, while there was no effect shown in vertical intensity.

An earthquake was recorded also by the magnetograph during the early morning of December 2, 1922. The characteristic earthquake effect is quite distinct on the curves of the declination and horizontal-intensity variometers, but very faint on the vertical-intensity variometer. All three curves indicate a short, sharp tremor occurring at $15^h\ 30^m$, but a slight swelling of the declination curve lasting for about one minute longer indicates that small tremors persisted a short while longer. The maximum range measured on the declination and horizontal-intensity curves is about 1 mm, but that on the vertical-intensity curve is too faint to measure. Various reports indicate the earthquake was local; it was distinctly felt by many people at Huancayo, but not at the ovservatory.

Two earthquakes were recorded also by the magnetograph during the night of April 25-26. The first occurred at $21^h\ 22^m$, April 25, and was recorded by all three variometers, although the effect in vertical intensity was very slight. The maximum range of the declination curve is 1.5 mm., of the horizontal-intensity curve, 2.5 mm., and of the vertical-intensity curve, 1.0 mm. The earthquake was local and was distinctly felt by all of the staff at the observatory, as well as by people at Chupaca and at Huancayo. There were two distinct shocks separated by about ten seconds in time; the horizontal-intensity record shows the two shocks plainly separated, but the other two curves do not. The second earthquake occurred at $2^h\ 42^m$, April 26, and, as appears from the magnetogram, was much feebler than the first. The record is quite distinct in declination, very faint in horizontal intensity, and not visible at all

[1]For other notes on earthquake records at Huancayo during October and November, 1922, see *Terr. Mag.*, vol. 27, 168, 1922.

in vertical intensity. The maximum range of the declination curve is 0.9 mm., and the horizontal-intensity curve shows only a slight blur.

All times are 75th meridian civil mean time.

W. F. WALLIS, *observer-in-charge.*

MAGNETIC AND ATMOSPHERIC-ELECTRIC DISTURBANCES AND AURORAL DISPLAYS, WESTERN AUSTRALIA, JANUARY 1923.

The records obtained at the Watheroo Magnetic Observatory show magnetic and atmospheric-electric disturbances concurrently with auroral displays visible in Western Australia during January 1923.

The records for all magnetic elements show very irregular movements between 19^h and 20^h January 20, which continue until approximately 15^h on January 21, when there is a gradual recovery from these irregular movements, which continues for several days.

The records of the electric conductivity of the atmosphere show disturbances as follows: January 19 at $21^h\ 28^m$, a rapid increase to about double former values; January 20 from $19^h\ 10^m$ to $19^h\ 25^m$, a rapid decrease to about half former values; January 21 from 18^h to 22^h, rapid and irregular movements, and January 23 at $6^h\ 49^m$, a sudden decrease of about one-third. The usual diurnal variation of positive and negative conductivities is such that a decrease is to be expected in these elements beginning any time in the morning or forenoon and continuing perhaps until evening, when there may be an increase to a maximum which is usually attained some time in the early morning hours.

Professor A. D. Ross, of the University of Western Australia, at Perth, summarizes the results of various reports regarding the auroral display received from observers in answer to his request as follows:

"I got quite a number of people to give me accounts of what they saw of the aurora. Most of the accounts came by telephone, and, generally speaking, they were quite vague. It is evident, however, that there was an aurora on the morning of January 21 from $0^h\ 15^m$ to $1^h\ 20^m$. It was not brilliant, showing only a general glow in the south and extending rather farther to the west than to the east. The aurora appeared again on the night of January 21, commencing apparently about 21^h or 22^h, but not at all brilliant until towards midnight. After midnight it became brilliant, and I have been in touch with people who saw it on till 3^h or $3^h\ 30^m$. About $1^h\ 30^m$ it showed the streamers mentioned in the newspapers most distinctly and also at times the pulsations of light running up the streamers."

All times are civil mean time for the 120th meridian east of Greenwich.

G. R. WAIT, *observer-in-charge.*

NOTES

1. *Principal Magnetic Storms at the Cheltenham Magnetic Observatory, January 1923 to March 1923.*[1]

Greenwich Mean Time		Range		
Beginning	Ending	Decl'n	Hor'l Int.	Vert'l Int.
h m	h m	′	γ	γ
Mar. 24, 9 ..	Mar. 25, 9 ..	44.7	183	204

2. *Errata, E. Schweidler article, Ueber die Selbstaufladung, 1922.*—Referring to previous volume of this Journal, the following corrections have been communicated by the author: Page 111, line 11 from bottom, read $z=0.8\frac{\alpha\text{-Strahlen},}{\text{cm}^2\ \text{sec}}$ instead of the latter, without the factor 0.8; p. 112, line 16 from bottom, instead of Pa read $\overline{P}a$; p. 117, line 15 from top, instead of $P=80$, read $P=150$ stat. Einh.; p. 117, line 22 from top, instead of $Q_a=\Pi_a$ read $Q_a=\Pi\alpha$.

3. *Terrestrial Magnetism and Atmospheric Electricity in France, 1923.—Prof. Ch. Maurain,* whom we are glad to welcome among the collaborators of the Journal, writes under date of March 1, 1923, as follows: "The printing of the volume which is to contain the results of the French observations 1914 to 1921 inclusive, will be completed in a few weeks. The second volume is in preparation and will be turned over to the printer in about a month. It is hoped that in the future there will be no delay in publication. In accordance with the resolution passed at the Rome meeting, I have had *atmospheric-electric observations* inaugurated at the Val Joyeux Observatory, where a small wooden structure has been constructed for the purpose. At present we are registering the potential gradient (radium collector, Benndorf electrometer), and are measuring the conductivity. We shall develop the installation progressively. The *magnetic survey work* is being continued for the new magnetic charts of France. In 1922 this work was performed by MM. Dongier, Eblé, Brazier, and myself, all four of us belonging to the Institut de Physique du Globe, and by Baldit (who took the place, for this work, of M. Mathias, who needed relief at that time). Besides, the Geographic Service of the Army is going to help us."

4. *International Geodetic and Geophysical Union.*—According to information received from the General Secretary, Col. H. G. Lyons, the countries which had joined the Union up to March 29, 1923, were as follows: Australia, Belgium, Brazil, Canada, Denmark, France, Greece, Holland, Italy, Japan, Mexico, Portugal, Siam, Spain, Switzerland, United Kingdom, and United States. Of these countries Denmark and Holland have only joined thus far the Section of Geodesy. Six other countries in Europe and South America have under consideration the question of their adherence to the Union.

[1]Communicated by E. Lester Jones, director, U. S. Coast and Geodetic Survey; Geo. Hartnell, Observer-in-Charge. Lat. 38° 44′.0 N.; Long. 76° 50′.5, or $5^h\ 07.^m4$ W. of Greenwich.

5. *National Geophysics Committee of Belgium, 1923.*—At a meeting on March 16 the Belgian Committee reorganized its officers: Col. Seligmann, director of the Military Cartographical Institute, was chosen president, and Mr. Somville, astronomer-in-charge of the seismological service at the Royal Astronomical Observatory, secretary. Messrs. P. Stroobant and Dehalu, who have discharged these functions since the establishment of the International Geodetic and Geophysical Union, had sent in their resignations; P. Stroobant has been elected president of the National Astronomical Committee of the Belgium Astronomical Union, and Mr. Dehalu has assumed the onerous duties of administrateur-inspecteur of the University of Liége. The Geophysics Committee has added to its membership, in order to form the new section of hydrography established at Rome in 1922, Messrs. Gilson, director of the Museum of Natural History, Van Mierlo, hydrographic engineer, and Van Brabandt, director of bridges and highways.

6. *American Geophysical Union, 1923.*—The American Geophysical Union, which is the American National Committee of the International Geodetic and Geophysical Union, had its fourth annual meeting, April 17 to 19, 1923. There were two business sessions, two general sessions, besides separate sessions for each of the 7 sections (Geodesy, Seismology, Meteorology, Terrestrial Magnetism and Electricity, Oceanography, Volcanology, and Geophysical Chemistry). At the opening general session on Tuesday morning, April 17, the following addresses were given: "The Organization and Aims of the National Research Council," by Dr. Vernon Kellogg, permanent secretary of the National Research Council; "The Organization and Work of the International Research Council," by Dr. R. A. Millikan, a delegate to the Brussels 1922 meeting; "The Organization and Aims of the American Geophysical Union," by the Chairman of the Union, Dr. Louis A. Bauer, and "The Organization and Aims of the National Geodetic and Geophysical Committee of Canada," by Noel Ogilvie, Esq., delegate from Canada. In the afternoon of the same day (April 17) a representative of each section gave an outline of the status, scope, and problems of concern to his respective section. In the evening there was a dinner for members and guests, at which brief addresses were made by the Hon. H. W. Temple on "Economic Value of Governmental Scientific Work," by Dr. E. E. Slosson on "Science and the Public," and by J. Patterson, Esq., "Greetings from Canada;" Capt. F. B. Bassett (Hydrographic Office), Col. E. Lester Jones (Coast and Geodetic Survey), and Prof. C. F. Marvin (Weather Bureau) also spoke on international and national work in geophysics.

At the section meetings there were presented reports of delegates to the Rome 1922 meeting and of special committees, and 49 papers on investigational topics. If judged by the very good attendance, both at the general and special sessions, and the interest shown, it would appear that the annual meeting has helped materially in the accomplishment of the objects of the American Union, namely: "To promote the study of problems concerned with the figure and physics of the Earth; to initiate and co-ordinate researches which depend upon international and national co-operation, and to provide for their scientific discussion and publication." In addition to a very satisfactory representation of the 65 members of the Union, there were present at the annual meeting three delegates from the National Geodetic and Geophysical Committee of Canada (Dr. W. Bell Dawson and Messrs. N. Ogilvie and J. Patterson), as well as representatives from interested governmental scientific bureaus and nearby universities. The National

Geophysics Committee of Mexico had also been invited to send a delegate, but owing to the fact that the members of the Mexican Committee were absent on field duty, it was not possible to have a representative from Mexico. For further information and list of present officers see this Journal, vol. 27, 1922, p. 80.)

7. *National Geophysics Committee of Spain.*—This Committee was organized this year under the presidency of *Sr. D. Antonio Izquierdo Valez,* Director-General of the Geographic Institute at Madrid and with a membership of 21 persons. The Committee has established 7 sections to conform to those of the International Geodetic and Geophysical Union. The officers of the Section of Magnetism are: president, *B. Cabrera Felipe;* vice-president, *L. Cubillo Muro;* and secretary, *Ubaldo Azpiazu.*

8. *Pan-Pacific Science Congress in Australia, 1923.*—The second meeting of this congress will be held in Australia (Melbourne and Sydney) from August 13 to September 3, 1923, under the auspices of the Australian National Research Council, Prof. D. Orme Masson, president. It will be recalled that the first meeting of the Congress was held at Honolulu in August 1920. The subjects to be dealt with are: Agriculture, Anthropology, Botany, Entomology, Geodesy and Geophysics, Geography, Geology, Hygiene, Meteorology, Oceanography, Radio-telegraphy, Veterinary Science, Vulcanology, Seismology, and Zoology. Every effort is being put forth by the Australian Council to make the forthcoming meeting of the Congress truly representative of all scientific workers interested in the Pacific.

9. *Carnegie Institution Combined Magnetometer and Earth Inductor.*—As the result of requests received from many countries for latest magnetic instruments, according to the designs and construction of the Department of Terrestrial Magnetism, arrangements have been made by which competent manufacturers, in the United States and abroad, may receive such assistance as required. Blue prints of drawings and, in certain instances, non-magnetic castings, are furnished by the Department at actual cost.

10. *Magnetic Surveys of Sweden, Finland, Norway, and Denmark.*—The following information has been received from Captain Gustaf Reinius, Hydrographer, Stockholm, Sweden, under date of April 7, 1923: Having received by the very kind assistance of the Director of the Department of Terrestrial Magnetism drawings of the "C. I. W. Combined Magnetometer and Earth Inductor," we have proceeded to make such an instrument. The other Scandinavian countries—Denmark, Finland, and Norway—will probably also make instruments of the same type. When the instrument is ready we have planned a survey of Sweden of the "first order" with stations over the whole country, which will thus for the first time be covered by a complete survey on uniform principles. From economical reasons the density of this first survey cannot be made greater than with an average distance between stations of 60-70 kilometers. The survey is expected to take about three years, and to begin in 1924 or 1925 at the latest. The detailed surveys made along the coast since some ten years will be continued, and the primary net is to be resurveyed in regular intervals.

The magnetic survey of Finland is near its completion, and in Norway a magnetic survey is planned. In Denmark the older measurements are to be completed by new ones.

11. *Proposed Scientific Work of MacMillan Arctic Expedition, 1923-1924.*—Dr. Donald B. MacMillan, well known for his Arctic work, will leave Wiscasset,

Maine, June 23, with his specially-built schooner *Bowdoin*, on an Arctic expedition during which he expects to cruise along the coast of Labrador to about latitude 55° north, thence across Davis Strait to the southwestern coast of Greenland, and along the west coast of Greenland to Etah and Cape Sabine. He hopes to arrive at Cape Sabine in time to proceed to Jones Sound, where he will establish winter quarters on the south coast of Ellesmere Land, but if for any reason he cannot reach Jones Sound, he will winter near Cape Sabine. Besides geographic and ethnological work, arrangements have been entered into with the Department of Terrestrial Magnetism of the Carnegie Institution of Washington for co-operative work in terrestrial magnetism, atmospheric electricity, and polar lights, along the lines successfully followed by Dr. MacMillan's Baffin Land Expedition of 1921-1922. The chief instrumental equipment will be supplied by the Department. Mr. R. H. Goddard, observer on the staff of the Department of Terrestrial Magnetism, and who was with Dr. MacMillan in 1921 to 1922, will accompany the Expedition and, with the assistance of Dr. MacMillan and other members of the Expedition's personnel, will carry out the proposed program of scientific observations.

While at the winter quarters, continuous observations in terrestrial magnetism and electricity will be made for a period of about eight months; special observations of polar lights will also be made. The magnetic observations will include determinations of secular variation at the C. I. W. stations in Greenland, Ellesmere Land, Baffin Land, and Labrador, and it is hoped that a number of additional magnetic stations may be occupied during the cruise and on sledge-trips from the winter quarters.

Dr. MacMillan is planning to return to the United States in the fall of 1924, his return route being along the northwest coast of Baffin Land and Labrador.

12. *Personalia.*—We note with regret the following deaths: *Stefan C. Hepites*, the first director and organizer of the Central Meteorological Institute of Rumania, at Braila, September 15, 1922, at the age of 71 years; *W. W. Bryant*, since 1904 in charge of the Meteorological and Magnetic Department of the Royal Observatory, Greenwich, on January 31, 1923, after a brief illness; *Count F. de Montessus de Ballore*, director of the Seismological Service of Chile since 1902, and professor at the Faculty of Sciences, Santiago; *Edward E. Barnard*, eminent astronomer and diligent observer of polar lights at the Yerkes Observatory on February 6, 1923, at the age of 66 years; and *Carl Hartvig Ryder*, the well-known director of the Danish Meteorological Institute, on May 3, 1923.

Victor F. Hess resigned his position as director of the research laboratory of the United States Radium Corporation, and has returned to the University of Graz to resume his duties as professor of experimental physics. He had been two years in the United States on furlough. *W. H. Eccles* has succeeded Admiral of the Fleet, Sir Henry Jackson, as president of the Radio Society of Great Britain. *Edward Kidson* was elected chairman of Section A of the Australasian Association for the Advancement of Science.

13. *International Meteorological Conference, Utrecht, 1923.*—The sixth international conference of directors of institutes and observatories will be held the second week of September 1923, at the invitation of Professor E. van Everdingen, director of the Meteorological Institute of Holland and in accordance with the 83rd resolution of the eleventh ordinary meeting of the International Meteorological Committee (London, September 1921).

LIST OF RECENT PUBLICATIONS

A. Terrestrial and Cosmical Magnetism.

ANTIPOLO OBSERVATORY. Hourly results of the observations made at the Magnetic Observatory of Antipolo near Manila, P. I., during the calendar year 1919. (Part IV of the annual report of the Weather Bureau for the year 1919.) Manila, Bureau of Printing, 1922 (47). 29 cm.

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GREENWICH, ROYAL OBSERVATORY. Curves of equal magnetic variation, 1922. Reduced to the epoch 1922 from observations by officers of His Majesty's Navy, and from surveys carried out by Colonial and Foreign Governments and by the Carnegie Institution of Washington. Sheet 1, Atlantic Ocean; sheet 2, Indian and Western Pacific Oceans; sheet 3, Eastern Pacific Ocean. Compiled by the Royal Observatory, Greenwich. London, Admiralty, Ncs. 2775, 2776, and 3777, Feb. 1, 1922. 65x98 cm.

GREENWICH, ROYAL OBSERVATORY. Curves of equal magnetic variation, 1922. Reduced to that epoch from observations by the officers of His Majesty's Navy and from surveys carried out by Colonial and Foreign Governments, and by the Carnegie Institution of Washington. With 3 insets showing approximate curves of equal magnetic variation for the north and south polar regions and the curves of approximate annual change of the magnetic variation in minutes of arc for the epoch 1922. Compiled by the Royal Observatory, Greenwich. London, Admiralty, No. 2598, Mar. 25, 1922. 45x97 cm.

GREENWICH, ROYAL OBSERVATORY. Curves of equal magnetic dip, 1922. Reduced to the epoch 1922 from observations by officers of His Majesty's Navy and from surveys carried out by Colonial and Foreign Governments and the Carnegie Institution of Washington. With 3 insets showing approximate curves of equal magnetic dip for the north and south polar regions and curves of approximate annual change of magnetic dip in minutes of arc for the epoch 1922. Compiled by the Royal Observatory, Greenwich. London, Admiralty, No. 3598, Mar. 25, 1922. 45x97 cm.

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VOLUME XXVIII NUMBER 3

TERRESTRIAL MAGNETISM

AND

ATMOSPHERIC ELECTRICITY

An International Quarterly Journal

September, 1923

Conducted by

LOUIS A. BAUER

With the Co-operation of Eminent Investigators.

CONTENTS

PUBLISHED FOR
THE JOHNS HOPKINS PRESS, BALTIMORE
THE ABINGDON PRESS, 420 PLUM ST., CINCINNATI, O.
THREE DOLLARS AND FIFTY CENTS A YEAR SINGLE NUMBERS, ONE DOLLAR
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THE ABINGDON PRESS
(Cash Subscription)
420 Plum St., CINCINNATI

Entered as second-class matter at the Post-office at Cincinnati

Terrestrial Magnetism
and
Atmospheric Electricity

VOLUME XXVIII SEPTEMBER, 1923 No. 3

ON THE DIURNAL VARIATION OF THE POTENTIAL GRADIENT OF ATMOSPHERIC ELECTRICITY.[1]

BY S. J. MAUCHLY.

Abstract.—New observations obtained aboard the *Carnegie* during the year ending November, 1921, increased by 50 per cent the observational data regarding the diurnal variation of the potential gradient over the oceans. A separate analysis of the new data has confirmed the results announced by the author in 1921[2] regarding the predominance, over the oceans, of a 24-hour wave progressing approximately according to universal rather than local time. It is found, however, that at least in the Pacific, there is also a well-defined secondary wave during the months of northern summer.

The present investigation has been extended to include also the diurnal variation of the potential gradient over the several continental areas. From harmonic analyses of the diurnal variation from many widely separated stations, varying in latitude from 78° north to 77° south, it is found that, despite the greater complexity of the variation over land, a large percentage of the stations considered show sufficiently good agreement with the ocean results to furnish strong evidence for the assumption of *a world-wide effect of 24-hour period progressing approximately according to universal time*. The average amplitude of this wave is about 20 per cent of the mean-of-day value and the average time of its greatest phase apparently varies somewhat with time of year, ranging from about 16^h to 19^h G. M. T.

While there are land stations in the tropical and temperate regions for which the analytical results are not in accord with the foregoing, there is considerable evidence indicating that this may be due to local disturbances of large amplitude rather than to an absence of the general phenomenon. The fact that for ϕ_2, the phase angle of the 12-hour wave at local midnight, marked departures from the all-stations mean are largely confined to places where the amplitude of the secondary wave is relatively small lends further support to the view that the limitations of harmonic analyses in the form here used may be partly responsible for the lack of more complete agreement between the land and ocean results.

1. Since the beginning of the fourth cruise of the non-magnetic yacht *Carnegie* early in 1915, the atmospheric-electric program aboard the vessel, in accordance with the plans of the Director of the Department of Terrestrial Magnetism, has included frequent 24-hour series of observations for determining the magnitude and diurnal variation of the potential gradient. Results obtained by the author in 1921,[2] based on an analysis of the observations from July 1915 to October 1920, indicated that the diurnal variation of the electric potential-gradient over the oceans was due, primarily, to a single wave of 24-hour period progressing approximately according to universal rather than local time.[3]

[1]Based upon two papers presented before the Section of Terrestrial Magnetism and Electricity of the American Geophysical Union, April 18, 1923, and the American Physical Society, April 20, 1923, respectively.

[2]*Bulletin of the National Research Council*, No. 17, pp. 73-77, Washington (1922), and *American Physical Review*, N. S. vol. 18, pp. 161-162 and 477, August and December, 1921.

[3]The first results of diurnal-variation observations abroad the *Carnegie* were published in 1917 (*Researches of the Department of Terrestrial Magnetism*, vol. 3, pp. 416-420) and from the limited number of observations then available it appeared that the diurnal variation of the potential gradient over the ocean was of a type very commonly observed at land stations, especially in temperate latitudes and in summer, namely, one characterized by two distinct maxima and two minima. As will be shown later, the difference between the conclusions of 1917 and those of 1921 is due chiefly to a difference in the method of reduction.

2. These preliminary results have since been confirmed by many additional observations from the *Carnegie* which have become available for study and comparison. In view of the far-reaching theoretical consequences involved in the existence in atmospheric electricity of an approximate universal-time effect of any considerable magnitude, it appeared desirable to carefully examine all data capable of throwing light on the nature of the diurnal variation of the potential gradient. Accordingly, the object of the present paper is twofold: (1) to give, in somewhat greater detail than heretofore, the results of the diurnal-variation observations aboard the *Carnegie* together with the methods employed in the analysis, and (2) to present the results of an examination of the accumulated data regarding the diurnal variation of the potential gradient from all land stations for which the records were available, especially as regards the characteristics of that component which has a 24-hour period.

RESULTS FROM OCEAN OBSERVATIONS ABOARD THE *CARNEGIE*.

3. The potential-gradient observations aboard the *Carnegie* during the Cruises IV, V, and VI (1915-21) have all been made with the mechanical-electrode type of apparatus described on pp. 380-383 of the 1917 report (l. c. in footnote 3). For the diurnal-variation observations the general procedure was to make a set of 20 observations during each of 24 consecutive hours. A set of 20 observations requires about 20 minutes and the mean value of the potential gradient derived from the set is referred to the mean time of the observations.

4. In order to secure mean diurnal-variation curves free from errors due to the large changes from day to day in the absolute value of the potential gradient, no series of observations was utilized unless it covered approximately an entire 24-hour period, and was complete or could be completed by justifiable interpolation. On this principle of selection it was necessary to reject many series which were terminated by the advent of unfavorable weather after having been continued throughout the greater part of a day, but it is believed that this loss was more than compensated by the fact that the data for each series utilized correspond to an actually occurring 24-hour sequence of the phenomenon under investigation. Moreover, the individual daily curves show, in general, a greater consistency than is usually found in land observations, and indicate the possibility of ob-

taining approximately correct mean curves from a smaller number of days than would normally be required for land observations.

5. The curves in Fig. 1 show the mean diurnal variation of the potential gradient as derived from 24 series of observations in the Pacific Ocean, 5 series in the Atlantic Ocean, and 10 in the Indian Ocean, respectively, when the usual method of tabulation is followed, all observations being referred to local time. That is, the first point on each of the curves of Fig. 1 represents the mean value of all the observations (from 24, 5, and 10 hourly sets, respectively), between midnight and 1^h L. M. T., referred to

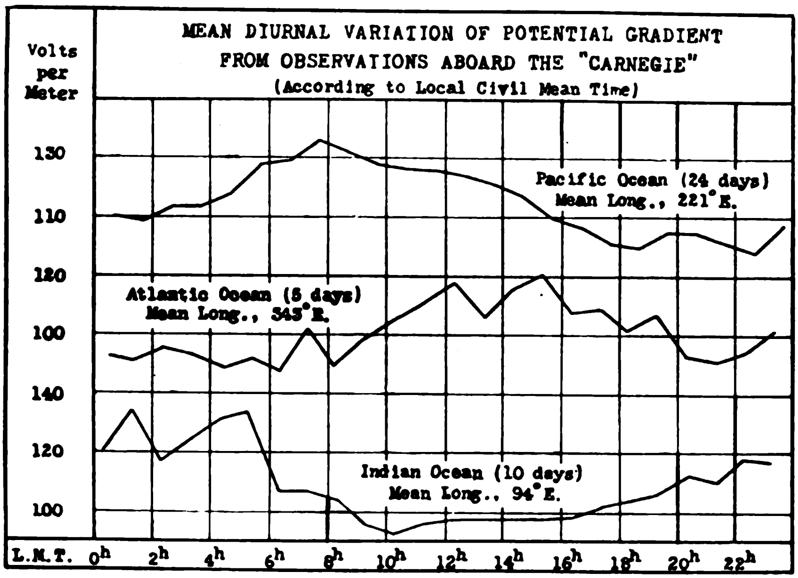

FIG. 1.

the corresponding mean time of observation, etc. It is obvious, from a comparison of these curves, not only that, for each of the major oceans, the principal component of the diurnal variation of the potential gradient consists of a 24-hour wave but also that the chief daily maxima, and minima, occur at very different times of the local day in the several oceans. For example, in the Pacific the average time of the occurrence of the chief maximum is in the forenoon, while in the Atlantic it occurs in the late afternoon, and in the Indian not until after midnight.[4]

[4]It is of interest in passing to note that in the Indian Ocean the observed maximum comes at a time of day when insulation difficulties are greatest and the corresponding minmum at the time when good insulation is most easily maintained.

6. However, if account is also taken of the differences between the respective means, for the several oceans, of the longitude positions in which the observations were made, these differences are found to correspond approximately to the observed differences in the local times at which the daily maximum occurs. While this suggested an approximately simultaneous occurrence of, say maximum, for each of the three oceans and, therefore, the propriety of referring observations directly to G. M. T., it seemed desirable to make a detailed test of the possibilities and results of such a procedure before deciding upon its general adoption.

7. For a rigorous test of the point in question we should, of course, utilize only data from simultaneous observations at stations differing considerably in longitude. While such a direct comparison of *Carnegie* observations was obviously not practicable, nevertheless some very interesting results were obtained by comparing the observational data from 5 pairs of ocean diurnal-variation series, where the longitude-difference for each pair of stations was about 180°. The 10 series were selected on the basis of their *longitude positions only* and with a view to their separation into two groups of 5 having relatively small longitude-differences between the members of each group.

TABLE 1.—*Dates and geographical coordinates of ten 24-hour series of the Carnegie potential-gradient observations.*

Group A			Group B			Long. Diff. (A-B)
Date	Lat.	Long.	Date	Lat.	Long.	
	°	°		°	°	°
1917, Feb. 20-21	51.6 S.	297.1 E.	1920, Oct. 8-9	45.2 S.	128.1 E.	169.0
1919, Dec. 30-31	15.8 S.	341.8 E.	1915, Sept. 16-17	13.8 N.	166.3 E.	175.5
1920, Mar. 16-17	30.4 S.	3.8 E.	1916, June 23-24	2.9 S.	187.6 E.	176.2
1920, Apr. 8-9	24.6 S.	345.7 E.	1915, Oct. 9-10	9.8 S.	162.7 E.	183.0
1920, Apr. 19-20	36.4 S.	6.4 E.	1916, May 26-27	32.6 S.	187.0 E.	179.4

Mean longitude for group A = 343° E.
Mean longitude for group B = 166 E.
Mean longitude-difference = 177

Table 1 gives the dates, geographical coordinates, and the adopted groupings of these series, and Fig. 2 the corresponding mean curves for each group separately, *A* and *B*, and for the two groups combined, *C*. It should be noted that, for curves *A*, *B*, and *C*, each individual 20-minute set of observations was referred to local time, just as were the observations represented by the

curves of Fig. 1, and that curve *C*, therefore, represents the ***local-time mean*** of the 10 series combined. The obvious phase difference of about 180° between curves *A* and *B* and the absence, in curve *C*, of any well-defined periodic variation, indicates at once both a predominance, during the observations here represented, of an effect progressing approximately according to universal time and

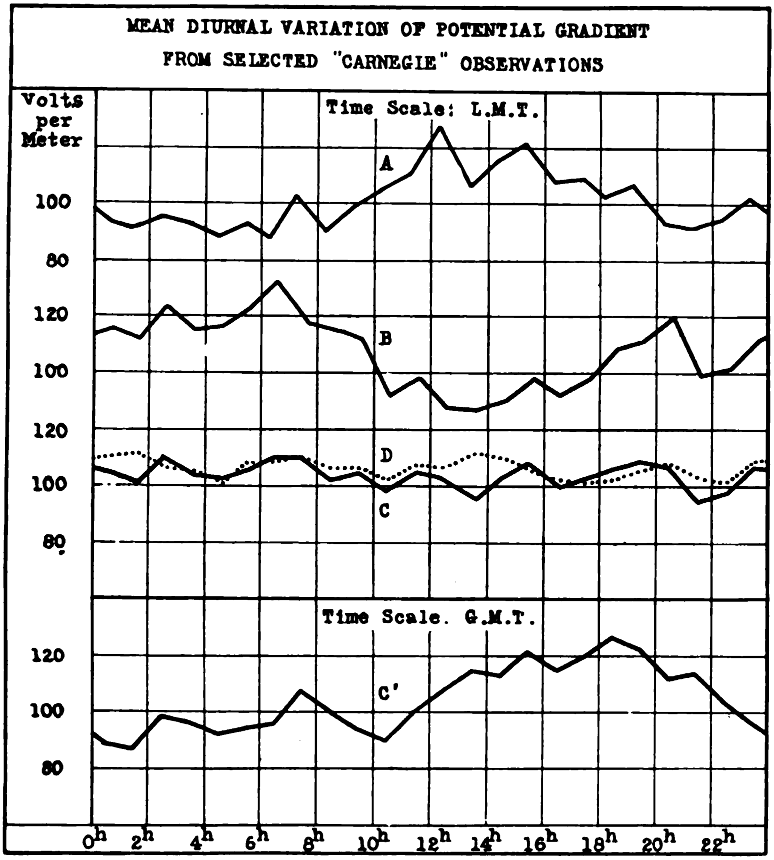

FIG. 2. (On curve A, the value at 12^h3 should be 118 V/m, instead of 128 as plotted.)

also the non-existence of any considerable local-time effects of world-wide occurrence. It will be seen later, from §§12 to 14, Fig. 4, and Table 2, that no serious error is introduced here by the obvious inability to take account of the widely different times of year represented by the observations paired in Table 1 and Fig. 2. (For explanation of curve *D*, see §18.)

8. Consideration of curves *A*, *B*, and *C*, of Fig. 2 leaves little room for doubting that the best approximation to the mean result of the 10 series of observations would be obtained by the adoption of a common basis of time. Accordingly, curve *C′* is the mean curve obtained from the same 10 series of observations as used for curve *C*, the only difference being that here each individual set of observations was referred to G. M. T. before tabulation. It is apparent, from curve *C′*, that the adoption of a common time basis is warranted and also that, so far as the *Carnegie* observations are concerned, a relatively small number of ocean series appear to give rather more dependable means than one would be likely to expect on the basis of experience with data from land observations.

9. In accordance with the conclusions drawn from Fig. 2 each 20-minute set of observations represented in Fig. 1 was referred to G. M. T. (civil) and re-tabulated on the new time basis. Fig. 3 shows, for each of the oceans, the mean diurnal variation resulting from this method of reduction. The full curve in the lower part of Fig. 3 is a general mean curve for the oceans, obtained by combining all the data represented in the separate curves for the Pacific, Atlantic, and Indian Oceans. (The broken curve at the bottom of Fig. 3 differs from the full curve only by the inclusion of data from the first six series of observations received from the *Carnegie* after the completion of the preliminary analysis.)

10. It was on the basis of the foregoing results that the conclusions were reached in 1921, that the diurnal variation of the potential gradient was of similar type over the three major oceans and that it was due primarily to a "wave" of 24-hour period which progressed approximately according to universal, rather than local, time. It was also pointed out, at that time, that the curves of Fig. 3 show a decided similarity to land results from high latitudes and to many of the winter curves obtained in temperate latitudes, provided account is taken of the differences in local time.

11. At the time the above conclusions were reached the *Carnegie* was making her sixth cruise and it was thus possible to arrange for an intensified program of diurnal-variation observations which was designed to yield (1) sufficient additional data for testing the previous results and (2) to fill in certain gaps in the distribution of the data as regards time of year and geographical position. As a result of this additional effort on the part of the observers during the last year of the cruise 20 additional

series were obtained which conformed to the previously adopted standard of excellence. ***The new material, constituting an addition of about 50 per cent to the available ocean data, was separately analyzed and found to confirm the earlier results,*** before it was incorporated into the general tabulations for strengthening the various ocean curves and for carrying out further investigations.

12. In view of our ignorance of the causes of the diurnal variation of the potential gradient considerable interest attaches itself to any knowledge we may be able to obtain regarding the constancy or possible variation of its characteristic features during the progress of the year. To shed light on this question the observa-

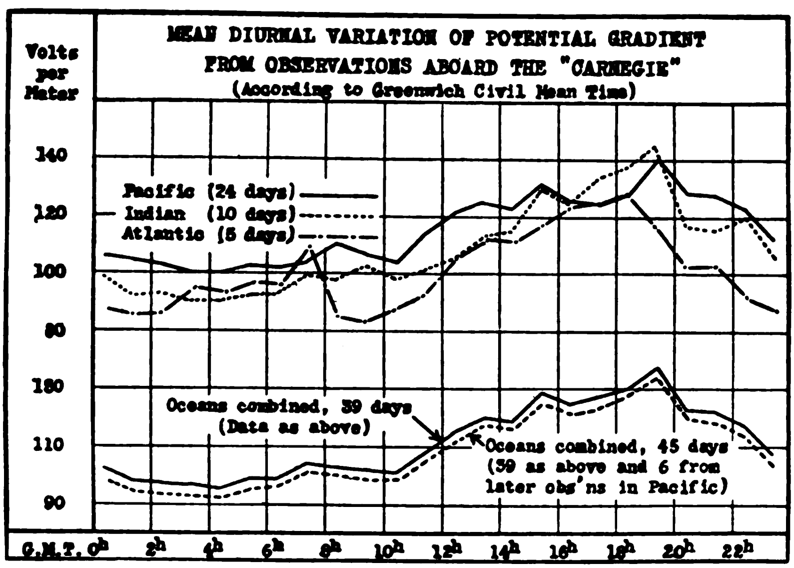

FIG. 3.

tional data from the *Carnegie* were divided into four groups representing 3-month periods symmetrical about the solstices and equinoxes. Thus there are 12 series representing February, March, and April, 13 series for May to July, and 17 series for each of the remaining quarters. The respective mean curves together with a curve of mean hourly values for the entire year are given in Fig. 4. It is, of course, realized, since these mean curves are not derived from observations made at one place or even in the same ocean, that they are only approximate and that they will undoubtedly be modified somewhat in detail when additional data become avail-

able.[5] On the other hand there is but little difference between the characteristic features of the corresponding quarterly curves obtained in 1921 from a total of 39 series and the present curves based on 50 per cent more observations.

13. In order to obtain approximate numerical measures of the characteristic features of the diurnal variation of the potential gradient as derived from the *Carnegie* observations and of their changes during the progress of the year and also to facilitate comparison between land and ocean results the data represented by the curves of Fig. 4 have been analyzed by the method of Fourier. Following the usual practice it is assumed that the value of the potential gradient P is given at any time by the expression

$$P = P_m + c_1 \sin(\theta + \phi_1) + c_2 \sin(2\theta + \phi_2) + c_3 \sin(3\theta + \phi_3) + \ldots \quad (1)$$

θ being counted from 0^h, midnight, G. M. T., at the rate of 15° per hour. The results of the analyses for the solstitial and equinoctial quarters and for the entire year are given in Table 2, where the amplitudes, c, are, however, expressed in percentages of P_m, the mean-of-day value. (It should be noted, as pointed out in footnote 5, that where absolute values of the potential gradient are given they are subject to an increase of the order of 20 per cent).

TABLE 2.—*Results of Fourier analysis of the diurnal variation of the potential gradient (P) from observations aboard the Carnegie 1915-1921.*

Months	P_m	ϕ_1	ϕ_2	ϕ_3	ϕ_4	c_1	c_2	c_3	c_4	c_2/c_1
	V/m	°	°	°	°	%	%	%	%	
Feb.-Apr.	114	197	273	208	352	19	4	1	1	0.24
May-July	94	163	209	119	223	10	7	2	1	0.72
Aug.-Oct.	97	168	218	250	337	16	4	1	2	0.24
Nov.-Jan.	105	204	225	243	14	14	2	4	1	0.15
Year	102	187	221	228	348	15	4	1	1	0.25

14. From Table 2, as from the curves of Fig. 4, it is obvious that the 24-hour wave continues, throughout the year, to be the predominating feature of the diurnal variation. Whether or not the apparent annual variation of ϕ_1 is real is, of course, a question whose settlement must await the results of further observational work over the oceans. However, it is of interest to note that the

[5] The *absolute values* of the potential gradient as given in Figs. 1, 2, 3, and 4 are all subject to an increase of the order of 20 per cent owing to the fact that most of the standardization observations could not be made until after the present reductions were well advanced. However, *all relative values are substantially correct.* Detailed publication of all diurnal-variation observations from the *Carnegie* reduced on the basis of the adopted factors will appear in a volume of the "Researches of the Department of Terrestrial Magnetism."

departures of ϕ_1 for the May-June-July quarter and the November-December-January quarter, respectively, from ϕ_1 for the yearly mean are similar in sense and magnitude to what is found at many land stations, as will be shown later.

As regards the amplitudes of the harmonics, the most striking

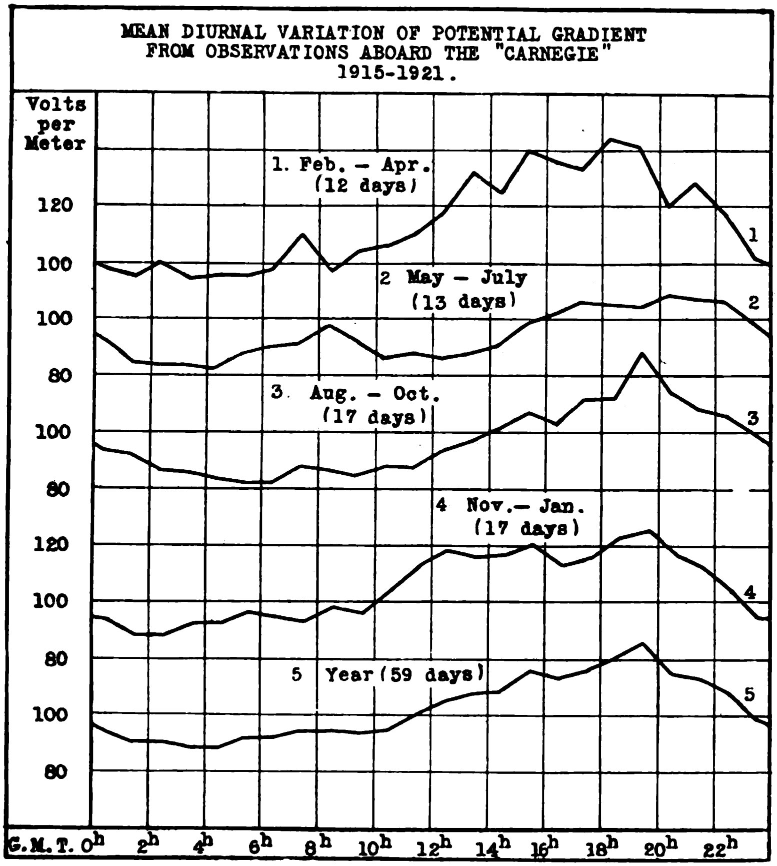

FIG. 4.

fact brought out by the analysis is the marked diminution of c_1 and increase of c_2 during the May-June-July quarter similar to what is observed at most land stations, the ratio c_2/c_1 during this quarter being, in fact, nearly 5 times as large as during the November-December-January quarter.

15. Unfortunately, the geographic distribution of the observations for the May-June-July quarter is not so good as one might

wish, since 11 of the 13 series of observations were made in a relatively small part of the Pacific Ocean (between latitudes 35°N. and 25°S. and longitudes 165°E. and 240°E.) and do not, therefore, represent the ocean as a whole. While the two remaining series, both of which were made in the Indian Ocean, show a secondary maximum at about 6^h to 8^h G. M. T., it is not so marked as in the observations from the Pacific. In order, however, to obtain the maximum amount of evidence from the data, a comparison was made of the mean diurnal variation during May, June, and July, as derived from 6 series of observations obtained in 1915-20, and 7 series made in 1921, respectively. The two subsidiary curves thus obtained were found to be almost identical in all essential features.

16. The close agreement of the May-July curve from observations prior to 1921 with that obtained from 1921 observations points rather strongly to the existence, at this time of year, of a 12-hour wave whose amplitude is large as compared with what is found for the other quarterly curves. It is, therefore, pertinent to inquire regarding the nature of the diurnal variation of the potential gradient *in this same region* during the remainder of the year. Fortunately, of the 17 series for August-October, 6 represent approximately the same region as the May-July curve; and of the 17 series for the November-January quarter, 7 were obtained in the area under discussion. In both cases the subsidiary mean curves resemble the yearly mean curve and the respective quarterly curves much more closely than they resemble the May-July curve. In other words, for the area in which the observations of May-July were made, the diurnal variation of the potential gradient during the six months of the year for which comparative data are available is practically identical with that derived from all oceans, as given in Fig. 4, for the same months. Consequently, so far as the Pacific Ocean is concerned, the evidence from the data in hand is entirely in favor of the reality of the double maximum type of curve for the May-July quarter. For the remainder of the year, however, the single-maximum type with only a small amplitude for the 12-hour wave appears to predominate for all oceans.

17. Attention was directed by Lüdeling[6] to the importance of ocean diurnal-variation observations for supplying evidence regarding the correctness of Ebert's[7] hypothesis of a causal relation between the diurnal-variations of the barometric pressure and the

[6] *Met. Zeit.*, vol. 23, 1906, pp. 115-121, especially p. 121.

[7] *Met. Zeit.*, vol. 21, 1904, pp. 201-213, especially p. 204.

potential gradient. Such evidence is especially desirable since it has been found by Chree[8] that the pressure curve at Kew, especially in the afternoon, shows a considerable lag with reference to the potential-gradient curve, whereas, according to Ebert's hypothesis the pressure curve should always lead. Although Neumayer[9] did not call attention to the fact, an examination of the published results of his registrations of both potential gradient and atmospheric pressure at Melbourne, 1858-'62, shows the same effect, the pressure curve in this case also lagging from 1 to 3 hours behind the potential-gradient curve. Despite the obvious need for evidence on this point from ocean observations, it turns out that no *direct* evidence is available from the observations to date, since the amplitude of the second harmonic over the oceans has been found large enough for definite comparisons only during the May-July quarter, which is also the quarter for which the regional distribution of the stations (as given in Section 15) is least favorable for such a study. This is due to the fact that, for the relatively limited region in which the May-July data were obtained, the two daily maxima occur on the average at about the same *local times* as in western Europe, since the difference in local time, with reference to the European stations, is of the order of 12 hours. Obviously, for such a condition, no assistance can be obtained from Fourier analysis since the value of ϕ_2 would be practically the same whether the observations were referred to G. M. T. or to local time. Further observations during the May-July quarter, in the Atlantic and Indian Oceans would supply valuable data both for determining whether the 12-hour wave observed in the mid-Pacific is local or world-wide in distribution and whether it progresses according to local or universal time.

18. However, if we assume the existence of both 24-hour and 12-hour waves the combination, according to local time, of observations from two stations differing in longitude by 180° should result in the neutralization of universal-time effects and the strengthening of local-time effects, provided, of course, that the same effects occur at both stations. Proceeding along this line, a study was made of the data in hand to determine (1) whether the 12-hour wave with an average amplitude of 4 per cent of the mean value (ranging from 2 per cent in December to 7 per cent in June) progresses more nearly according to local or universal time; and (2)

[8] *Phil. Trans.*, Series A, vol. 206, pp. 299-334, paragraph 27.

[9] *Meteorological and Magnetical Observations, Flagstaff Observatory*, 1858-1863, Mannheim, 1867, Plates 5 and 7 of Appendix.

whether there is evidence of any other local-time components of world-wide occurrence. For this purpose, a separate study was made of the diurnal-variation observations from 24 selected days (12 pairs), the places of observation represented by each pair differing in longitude by approximately 180°. Curve *D*, the dotted curve, of Fig. 2, is the mean curve, *according to local time*, of these "compensated observations." (Obviously, curves *C* and *D* of Fig. 2 differ only with respect to the number of observational series which they represent). While an examination of curve *D* indicates a local-time wave of small amplitude and approximately 6-hour period there is no evidence of any other wave of appreciable amplitude. According to Fourier analysis, the 6-hour wave has an amplitude of about 3 per cent of the mean-of-day value, P_m, and its phase angle, at local midnight, is zero.

19. The results just stated, so far as they go, indicate: (1) that the 12-hour wave of the diurnal variation of the potential gradient over the ocean, like the 24-hour wave, is approximately a universal time phenomenon, as one would indeed be led to infer from the fact that the corresponding phase angles (ϕ_2 of Table 2) are nearly constant notwithstanding the relatively large differences in the local times of the stations at which the observations were made; (2) as regards the 6-hour wave, which apparently is the only local time wave of general occurence over the oceans, both the amplitude and phase angle are in as close agreement with the results obtained by Bauer[10], from his analysis of the Ebro potential-gradient data for 1910-20, and those of Chree[11], based on the Kew data from 1898-1912, as one could expect from the limited observational data available for investigation. Whether the results obtained with reference to the 6-hour wave are representative of an actual phenomenon or simply the effect of a fortuitous combination of observations is another question which must await, for answer, the accumulation and study of more observational data. Similarly, the amplitude of the 12-hour wave over the oceans is in general so small that its failure to show up under the method of securing local-time means from non-simultaneous "compensated observations" does not by any means prove that it occurs over the oceans as a universal-time phenomenon. In fact, owing to the relatively small number of "compensated" series now available, the most important positive result coming from this method of attack is the unmistakable evidence which it furnishes

[10] *Terr. Mag.*, vol. 27, 1922, pp. 1-30, Table 14 and paragraph 40.

[11] *Phil. Trans.*, Series A, vol. 206, 1906, pp. 299-334, paragraph 15, and vol. 215, 1915, pp. 133-159, paragraph 12.

with reference to the progress of the 24-hour wave approximately according to universal rather than local time, and the absence of major local-time effects of general occurrence.

RESULTS FROM OBSERVATIONS AT LAND STATIONS.

20. *With the confirmation, from new and independent observations, of the occurrence in the diurnal variation of the potential gradient over the oceans of a 24-hour wave progressing approximately according to universal time, increasing interest attaches to the investigation of the possible occurrence of a similar phemonenon at land stations.* In view of the prevalence at most land stations of appreciable (sometimes very large) local effects, a direct examination of the observed variations is not suitable for this purpose. It is believed, however, that the method of Fourier analysis, despite its limitations, offers the most satisfactory means of obtaining evidence calculated to throw light on this subject. Accordingly, a comparison has been made of all available Fourier analyses of the diurnal variation of the potential gradient as published by various investigators from time to time, together with the results of many new analyses, made in the Department of Terrestrial Magnetism, based partly on unpublished data and partly on published data which had not, heretofore, been thus utilized. It is, of course, obvious that there can be no uniform standard of reliability in such an aggregation of observational and analytical results, but it is believed that the present purpose will be best served by a comparison of available data without specific differentiation between those based on series of many years in extent and those based upon observations of only a few months duration. Likewise, no attempt is made, at this time, to distinguish between stations as regards excellence of equipment and suitability of locations.

21. To facilitate the comparison of data from various localities and also to obtain as much information as possible regarding possible changes in the nature of the diurnal variation during the course of the year, a separate tabulation has been made for each of four portions of the year approximately symmetrical about the equinoctial and solstitial months. (Tables 3, 4, 5, and 6). Although the mean diurnal variation for the year possesses much less value where considerable change occurs in the diurnal variation during the year than where its characteristics remain nearly constant, there is also given, in Table 7, a comparison of the mean diurnal variation for the year, at various stations. The chief value of

Table 7 lies in the fact that it brings under comparison a number of stations and regions for which only the mean-annual data are available.[12]

22. The material summarized in Tables 3 to 7, inclusive, is based on the assumption that the value of the potential gradient P is given by the expression (1) of §13, θ being here taken as zero at local midnight. The main comparison of stations is, however, between the respective phase angles of the first harmonic (24-hour wave) at 0^h, midnight, G. M. T., rather than on the corresponding phase angles at local midnight. The G. M. T. corresponding to the maximum phase of the 24-hour wave is given also as a somewhat more convenient quantity for direct comparison. *The symbols used in Tables 3-7* are briefly as follows; ϕ_1, the phase angle of the first harmonic at local midnight; $\bar{\phi}_1$, the phase angle of the first harmonic at 0^h, midnight, G. M. T.; G_1, the G. M. T. (civil) corresponding to the maximum phase of the 24-hour wave; ϕ_2, the phase angle of the 12-hour wave at local midnight; and P_m, c_1, c_2, respectively, the mean-of-day value, and amplitudes of the 24-hour and 12-hour waves, expressed in percentages of P_m.

23. From an inspection of Tables 3 to 7, inclusive, it is evident that in each case the range of $\bar{\phi}_1$ is less than the range of ϕ_1 and also that the mean departure of the values of $\bar{\phi}_1$ from its mean value is,

TABLE 3.—*Results of Fourier analysis of the diurnal variation of the potential gradient for months of northern spring.*

Place	Months	Years	Lat.	Long.	ϕ_1	$\bar{\phi}_1$	G_1 (G.M.T.)	ϕ_2	c_1	c_2	c_2/c_1
			°	°	°	°	h	°	%	%	
Karasjok......	Feb.-Apr..	1904	69.3N	25.6E	176	202	16.5	151	32	21	0.65
Edinburgh.....	Mar....	1912	55.9N	3.2W	276	273	11.8	185	17	16	0.95
Potsdam......	Mar....	1904-08	52.4N	13.1E	264	277	11.5	175	6	10	1.59
Kew..........	Mar....	1905-12	51.5N	0.3W	183	183	17.8	180	10	19	1.85
Munich.......	Mar....	1905-10	48.1N	11.6E	249	261	12.6	180	19	24	1.27
Kremsmünster.	Mar....	1902-11	48.0N	14.1E	208	222	15.2	178	31	11	0.37
Davos........	Feb.-Apr..	1909-10	46.8N	9.8E	220	230	14.7	205	19	22	1.16
Ebro..........	Mar....	1910-20	40.8N	0.5E	212	213	15.8	188	17	14	0.83
Washington....	Apr.....	1918-21	39.0N	77.1W	275	198	16.8	171	18	12	0.66
Melbourne.....	Mar.....	1858-62	37.8S	145.0E	70	215	15.7	210	24	31	1.30
Petermann I...	Mar.-May.	1909	65.2S	64.2W	230	166	18.9	358	30	7	0.25
Carnegie.......	Feb.-Apr..	....	......	....	...	197	16.9	...	19	4	0.24

[12] In general, the data utilized in the preparation of Tables 3 to 7 were obtained either from official observatory publications or from memoirs regarding the work of special expeditions, and most of the sources can thus be located from a knowledge of the places and dates as given in the tables. In addition, some of the data, including the results of various analyses, were obtained from scientific books and periodicals, while the data given for Bowdoin Harbor (the winter quarters of the MacMillan Baffin Land Expedition of 1921-'22) and for Washington are based on preliminary reductions of unpublished data from observations by the Department of Terrestrial Magnetism. Full references to all sources consulted will be given in a forthcoming monogram on this subject which will appear in "Researches of the Department of Terrestrial Magnetism."

TABLE 4.—*Results of Fourier analysis of the diurnal variation of the potential gradient for months of northern summer.*

Place	Months	Years	Lat.	Long.	ϕ_1	$\bar{\phi}_1$	G_1 (G.M.T.)	ϕ_2	c_1	c_2	c_2/c_1
			°	°	°	°	h	°	%	%	
Cape Bismark..	June, July.	1908	76.8N	19.0W	209	190	17.3	238	45	8	0.19
Karasjok......	May-July..	1904	69.3N	25.6E	141	167	18.9	144	16	9	0.56
Edinburgh.....	Apr.-Sept..	1912	55.9N	3.2W	268	265	12.3	193	9	15	1.75
Potsdam......	June....	1904–08	52.4N	13.1E	35	48	2.8	191	16	14	0.90
Kew..........	May-Aug..	1898–1912	51.5N	0.3W	113	113	22.5	185	4	22	5.00
Paris..........	May-Aug..	1894–98	48.8N	2.3E	95	97	23.5	197	13	20	1.54
Eiffel Tower...	May-Aug..	1896–98	48.8N	2.3E	216	218	15.5	171	13	8	0.64
Munich.......	June....	1905–10	48.1N	11.6E	307	319	8.7	191	24	23	0.95
Kremsmünster.	Apr.-Oct...	1902–11	48.0N	14.1E	231	245	13.7	196	19	15	0.78
Sonnblick.....	June-July..	1902	47.3N	12.6E	173	186	17.6	142	16	11	0.65
Davos........	May-July .	1909–10	46.8N	9.8E	296	306	9.6	227	19	30	1.52
Lyons.........	June-Aug..	1885–90	45.8N	4.8E	256	261	12.6	188	13	18	1.43
Trieste........	June-Aug..	1904	45.6N	13.8E	236	250	13.3	191	54	15	0.29
Ebro..........	June....	1910–20	40.8N	0.5E	154	154	19.7	196	6	17	2.78
Baltimore.....	Apr.-July..	1887	39.3N	76.6W	228	151	19.9	307	13	7	0.56
Washington....	July....	1918–21	39.0N	77.1W	220	143	20.5	184	12	12	1.03
Algiers........	May-Aug..	1912–17	36.8N	3.1E	236	239	14.1	162	17	8	0.50
Batavia.......	Apr.-Sept..	1887–90	6.2S	106.8E	78	184	17.7	219	61	18	0.29
Rio de Janeiro..	Mar.-Aug..	1911	22.9S	43.2W	278	235	14.3	151	20	15	0.75
Melbourne.....	June....	1858–62	37.8S	145.0E	244	29	4.1	197	9	28	3.33
Petermann I...	June-Aug..	1909	65.2S	64.2W	219	155	19.7	320	18	4	0.23
Cape Evans....	May-July..	1911	77.6S	166.4E	8	174	18.4	209	15	6	0.42
Carnegie.......	May-July..	....	......	....	...	163	19.1	...	10	7	0.72

TABLE 5.—*Results of Fourier analysis of the diurnal variation of the potential gradient for months of northern autumn*

Place	Months	Years	Lat.	Long.	ϕ_1	$\bar{\phi}_1$	G_1 (G.M.T.)	ϕ_2	c_1	c_2	c_2/c_1
			°	°	°	°	h	°	%	%	
Karasjok......	Aug.-Oct..	1903–04	69.3N	25.6E	170	196	16.9	184	22	18	0.83
Potsdam......	Sept....	1904–08	52.4N	13.1E	187	190	17.3	163	2	18	9.09
Kew..........	Sept....	1905–12	51.5N	0.3W	197	197	16.9	195	15	18	1.25
Paris..........	Sept.-Oct..	1891–98	48.8N	2.3E	182	184	17.7	213	14	21	1.47
Eiffel Tower...	Sept.-Oct..	1895–98	48.8N	2.3E	212	214	15.7	185	16	4	0.23
Munich.......	Sept....	1905–10	48.1N	11.6E	258	270	12.0	191	20	28	1.41
Kremsmünster.	Sept....	1902–11	48.0N	14.1E	224	238	14.1	200	16	16	0.99
Davos........	Aug.-Oct..	1909–10	46.8N	9.8E	248	258	12.8	209	14	31	2.22
Ebro..........	Sept....	1910–20	40.8N	0.5E	203	204	16.4	193	16	18	1.10
Washington....	Oct.....	1918–21	39.0N	77.1W	237	160	19.3	176	32	11	0.36
Melbourne.....	Sept....	1858–62	37.8S	145.0E	66	211	15.9	211	15	30	1.96
Petermann I...	Sept.-Nov.	1909	65.2S	64.2W	220	156	19.6	353	30	5	0.17
Cape Evans....	Aug.-Oct..	1911	77.6S	166.4E	346	152	19.9	202	10	7	0.63
Carnegie.......	Aug.-Oct..	....	......	....	...	168	18.8	...	16	4	0.24

TABLE 6.—*Results of Fourier analysis of the diurnal variation of the potential gradient for months of northern winter.*

Place	Months	Years	Lat.	Long.	ϕ_1	$\bar{\phi}_1$	G_1 (G.M.T.)	ϕ_2	c_1	c_2	c_2/c_1
			°	°	°	°	h	°	%	%	
Karasjok	Nov.-Jan.	1903–04	69.3N	25.6E	189	215	15.7	155	35	14	0.41
Edinburgh	Oct.-Mar.	1912	55.9N	3.2W	222	219	15.4	161	21	6	0.30
Potsdam	Dec.	1904–08	52.4N	13.1E	206	219	15.4	179	22	5	0.25
Kew	Nov.-Feb.	1898–1912	51.5N	0.3W	209	209	16.1	181	12	11	0.90
Paris	Nov.-Feb.	1895–99	48.8N	2.3E	223	225	15.0	206	22	10	0.47
Munich	Dec.-Feb.	1905–10	48.1N	11.6E	241	253	13.1	187	26	15	0.56
Kremsmünster	Nov.-Mar.	1902–11	48.0N	14.1E	212	226	14.9	172	30	13	0.43
Davos	Nov.-Jan.	1909–10	46.8N	9.8E	217	227	14.9	189	35	16	0.44
Lyons	Dec.-Feb.	1885–90	45.8N	4.8E	220	225	15.0	183	13	10	0.76
Trieste	Dec.-Feb.	1904–05	45.6N	13.8E	226	240	14.0	212	55	5	0.09
Ebro	Dec.	1910–20	40.8N	0.5E	224	224	15.1	193	22	9	0.40
Baltimore	Oct.-Feb.	1885–86	39.3N	76.6W	255	178	18.1	239	14	9	0.66
Washington	Jan.	1918–21	39.0N	77.1W	257	180	18.0	161	19	9	0.48
Algiers	Nov.-Feb.	1912–17	36.8N	3.1E	234	237	14.2	114	32	8	0.26
Batavia	Oct.-Mar.	1887–90	6.2S	106.8E	70	177	18.2	220	64	23	0.36
Rio de Janeiro	Sept.-Feb.	1910–11	22.9S	43.2W	286	243	13.8	171	32	23	0.72
Melbourne	Dec.	1858–62	37.8S	145.0E	63	208	16.1	210	25	24	0.96
Cape Evans	Nov.-Jan.	1911–12	77.6S	166.4E	66	232	14.5	243	21	4	0.22
Carnegie	Nov.-Jan.	...	...	...	...	204	16.4	...	14	2	0.15

TABLE 7.—*Results of Fourier analysis of the diurnal variation of the potential gradient from mean hourly values for entire year.*

Place	Years	Lat.	Long.	ϕ_1	$\bar{\phi}_1$	G_1 (G.M.T.)	ϕ_2	c_1	c_2	c_2/c_1
		°	°	°	°	h	°	%	%	
Cape Thordsen	1882–83	78.5N	15.7E	178	194	17.1	230	7	3	0.47
Karasjok	1903–04	69.3N	25.6E	177	203	16.5	158	28	17	0.59
Bowdoin Harbor	1920–21	64.4N	78.0W	291	213	15.8	202	28	1	0.04
Edinburgh	1912	55.9N	3.2W	233	230	14.7	183	14	10	0.72
Eskdalemuir	1916	55.3N	3.2W	120	117	22.2	177	15	10	0.64
Kew	1898–1912	52.5N	0.3W	190	190	17.3	187	8	16	2.08
Munich	1905–10	48.1N	11.6E	250	262	12.5	190	23	21	0.90
Kremsmünster	1902–11	48.0N	14.1E	221	235	14.3	188	24	13	0.56
Trieste	1902–05	45.6N	13.8E	236	250	13.3	155	55	6	0.12
Perpignan	1886–88	42.6N	2.9E	201	204	16.4	210	16	18	1.08
Baltimore	1885–86	39.3N	76.6W	253	176	18.3	287	12	7	0.60
Washington	1918	39.0N	77.1W	261	184	17.7	166	18	12	0.64
Tokyo	{1897–98, 1900–01}	35.7N	139.8E	43	183	17.8	218	30	30	1.00
Batavia	1890–1900	6.2S	106.8E	84	191	17.3	210	49	31	0.63
Rio de Janeiro	1910–11	22.9S	43.2W	283	239	14.1	161	25	18	0.72
Melbourne	1858–62	37.8S	145.0E	65	210	16.0	206	13	28	2.13
Cape Evans	1911–12	77.6S	166.4E	33	199	16.7	228	14	6	0.42
Carnegie	1915–21	...	...	...	187	17.5	...	15	4	0.25

in each table less than the corresponding quantity for ϕ_1. Moreover, the reduction in ranges and mean departures from the average values are very appreciable in all cases except for the months corresponding to summer in the Northern Hemisphere (Table 4). However, ranges and average departures for this quarter, based only on data from stations at which $c_2/c_1 < 0.67$, show as great reductions in going from ϕ_1 to $\bar{\phi}_1$ as do those for the remainder of the year. To further facilitate comparison of the land results for different parts of the year and also the comparison of land and ocean results, Tables 3 to 7, inclusive, are summarized in Table 8.

TABLE 8.—*Summary of mean results derived from Tables 3 to 7, inclusive.* (All symbols as in the preceding tables and as given in §22.)

Table	Mean Month (approximate)	Range		Av. Depart. from Mean		$\bar{\phi}_1$ Mean	G_1 (Mean)		
		ϕ_1	$\bar{\phi}_1$	ϕ_1	$\bar{\phi}_1$		All Stations	$c_2/c_1 < 0.67$	Ocean (*Carnegie*)
		°	°	°	°	°	h	h	h
3	March......	206	111	41	28	222	15.2	16.8	16.9
4	*June........	299	290	68	59	188	15.3	17.2	19.1
		(228)	(99)	(60)	(26)	(191)			
5	September...	280	118	41	28	202	16.5	18.6	18.8
6	December...	223	76	46	16	219	15.4	15.5	16.4
7	January to December	258	145	69	24	205	16.3	16.9	17.5

*The quantities enclosed in parentheses are special means for Table 4, based only on stations for which $c_2/c_1 < 0.67$.

24. From Table 8 it appears that there is good evidence for concluding that the 24-hour wave in the diurnal variation of the potential gradient progresses approximately according to universal rather than local time, and that the time of its maximum development is, *as a first approximation*, nearly constant throughout the year and the same over land and ocean areas. There are, to be sure, many stations at which the observations show large deviations from this general law, either in having a different, though fairly constant, time at which the 24-hour wave reaches its maximum, as for example, Munich and Edinburgh, or in having a large annual variation in ϕ_1 and G_1, as well illustrated by Kew, Melbourne, Paris, and Potsdam. In general, however, the stations which show the greatest departures from the mean result are those at which relatively large local effects obviously introduce considerable uncertainty as to the phase angle ϕ_1.

25. Although the approximate constancy of $\bar{\phi}_1$ and G_1, through-

out the year, may be taken as the outstanding feature of Table 8, there are, as already stated in Section 15, some indications of an annual variation in these quantities deserving further notice. For example, in each of the last two columns of Table 8, that is, both for land and ocean data, there is a range of about 3 hours in the values of G_1 (*Mean*); also, in each column, the arithmetic mean of the "June" and "September" values of G_1 (*Mean*) exceeds the arithmetic mean for the "March" and "December" quarters by about 2 hours. In other words, the mean analytical results both from the *Carnegie* observations and from all land stations where $c_2/c_1 < 0.67$ indicate an *average* annual change of about 2 or 3 hours in the value of G_1, the maximum of the 24-hour wave occurring earlier by that amount during the months of northern winter and spring than during the months of northern summer and autumn. From the *Carnegie* data alone, one might be inclined to regard this result as an accidental outcome which would vanish with the accumulation of more observational data. However, the consistency of the *Carnegie* results from the several cruises is good on this point, and the agreement of the land stations among themselves is the more remarkable when it is noted that approximately the same annual shift occurs at stations in the Northern and Southern Hemispheres and in each of the major continents. While individual exceptions are frequent, the general result is of sufficient interest and importance to justify its consideration as one of the factors which may need to be taken account of in a general theory of atmospheric electricity.

26. In view of the facts noted in Section 17, regarding a possible relation between the diurnal variations of potential gradient and atmospheric pressure, the approximate constancy of the phase angle of the 12-hour wave, ϕ_2, at *local* midnight is of especial interest. Although there are several exceptions, the tables in general indicate that the values of ϕ_2 which depart most widely from the usually occurring mean values (180° to 200°) are those from stations for which c_2/c_1 is relatively small, which is, of course, what one would expect.

27. Several other features not obvious from the tables should be mentioned in passing: For example, although both Kew and Potsdam show a very marked change in the phase angle of the 24-hour wave during the course of the year, the changes are not in the same sense. That is, at Kew the maximum phase of the 24-hour wave occurs some 5 or 6 hours *later* in June than in January,

while at Potsdam it occurs about 14 or 15 hours *earlier* in June than in January. Since these stations differ very little in either latitude or longitude and since their respective values of G_1 differ by less than an hour in December there seems little doubt that local conditions play an important role in the diurnal variation at both places, especially during the months of northern spring and summer. Although the reversed effect observed at Potsdam is also in evidence at Melbourne and, to a much smaller degree, at several other stations, the most frequently occurring type of annual change in G_1 is that suggested by the ocean results and of which Kew and Paris are extreme cases. However, from a comparison of the data from Tables 3 to 6, inclusive, it is obvious that there are numerous regions in which G_1 remains nearly constant throughout the year or shows only a small change similar to that found from the ocean data.

Another point of interest is that at Melbourne, a temperate-zone station in the Southern Hemisphere, the largest values of c_2/c_1 occur during the same months as at most stations in the Northern Hemisphere, and the maximum departure of G_1 from the general average value also occurs during these same months; that is, during the same months as at Kew, Potsdam, and Paris.

28. The author's best thanks are due Dr. Louis A. Bauer, Director of the Department of Terrestrial Magnetism, at whose suggestion the reduction and study of the ocean observations were taken up, both for his continued interest and encouragement and for the use of the results of numerous Fourier analyses from his own investigations. The utmost credit is also due each of the several commanders of the *Carnegie* and the various observers upon whom fell the responsibility and burden of making such extensive diurnal-variation observations at sea. In this connection, especial mention should be made of the pioneer work of Mr. H. F. Johnston who was responsible, for the practical working out of the diurnal-variation program aboard the vessel during the early part of Cruise IV and to Captain J. P. Ault and Observor Andrew Thomson, who by their indefatigable efforts, made half as many diurnal-variation observations during the last 12 months of Cruise VI as had been obtained during the period 1915-20, inclusive, thus providing the new data required for confirmation of the original results. Finally, the author is under obligation to all who assisted in the various stages of the reduction work, but especially to Dr. G. R. Wait for assistance in the original reductions of 1920 and to

Mr. C. C. Ennis and Miss Mary C. Parker for their valuable assistance in the later reductions including many analyses of data from land stations. Mr. Ennis also prepared the diagrams appearing in this paper.

SUMMARY AND CONCLUSIONS.

30. *a.* In confirmation of the results of a preliminary analysis published in 1921 it is found that the preponderance of evidence from observations made aboard the *Carnegie* in each of the major oceans, indicates that *the diurnal variation of the potential gradient over the oceans is primarily due to a 24-hour "wave", which progresses approximately according to universal rather than local time.* According to the mean yearly results, from all ocean observations to date, this primary wave has an amplitude of about 15 per cent of the mean-of-day value of the potential gradient and attains its maximum development at about $17^h.5$ G. M. T.

b. Although the phase angle of the 24-hour wave at 0^h G. M. T. remains approximately constant throughout the year there is some evidence of a small, though not negligible, annual variation in this quantity, corresponding to the development of the potential-gradient maximum in the months of northern summer somewhat later than in the months of northern winter. This annual shift of the time of maximum appears to be of the order of 2 to 3 hours.

c. Only in the mid-Pacific has it been possible to follow up the changes in the diurnal variation throughout the year in a given region. Here the results to date indicate, during the months corresponding to mid-summer in the Northern Hemisphere, a considerable reduction in the amplitude of the 24-hour wave and the development of a 12-hour wave whose amplitude (c_2) is about 70 per cent as great as that of the 24-hour wave (c_1). The double-daily maxima of the 12-hour wave occur *in the mid-Pacific*, at approximately the same local time as at most land stations. During the remainder of the year, however, the total diurnal variation is found to be practically the same for each of the major oceans, the amplitude of the 12-hour wave being, in each case, relatively small.

d. Lack of the requisite observations in the Atlantic and Indian Oceans during the months of northern summer makes it impossible to say, at present, whether or not the 12-hour wave, in these oceans and at this time of year, assumes a relatively large amplitude as it does in the Pacific. Similarly, and for the same reasons, it can not be determined, for the present, whether the 12-hour wave over the oceans progresses according to local or universal time.

e. The results of a special method of investigation suggest the possible occurrence over the ocean of a local-time wave of small amplitude and 6-hour period similar to that indicated for Ebro and Kew by the investigations of Bauer and Chree, respectively.

f. From comparison of the phase angles of the 24-hour wave

as obtained from the Fourier analysis of the observational data from many *widely-distributed land stations*, it is shown: (1) that the respective values of this phase angle at 0^h, midnight, G. M. T., $\bar{\phi}_1$, are in much better accord than are the corresponding values, ϕ_1, at local midnight; (2) that, for the majority of the stations compared, the mean G. M. T. at which the maximum of the 24-hour wave occurs does not differ greatly from the corresponding time derived from the ocean observations as noted under *a*; and (3) that at most of the stations which appear to be least affected by local disturbances, there is an average tendency toward an annual variation in the phase angle of the 24-hour wave at 0^h G. M. T., similar in sense and magnitude to that indicated by the *Carnegie* results, noted under *b*.

g. The comparison of the analytical results also shows: (1) that the land stations which show the greatest values of c_2/c_1 are in general, though not always, the ones which show, for the value of the phase angle of the 24-hour wave at 0^h G. M. T., the greatest departures from the mean for all stations, and (2) that for ϕ_2, the phase angle of the 12-hour wave at local midnight, the greatest departures from the mean value for all stations are usually found at those stations for which c_2/c_1 is relatively small. Accordingly, a study of the phase angles of either the primary or the secondary wave is not likely to give either consistent or reliable results unless account is also taken of the ratio of the amplitudes.

h. Only during the months corresponding to mid-summer in the Northern Hemisphere does there appear to be any serious obstacle to the general acceptance of a world-wide and approximately universal-time effect in the diurnal variation of the potential gradient, and even during this part of the year the results from a large percentage of the stations compared are in sufficiently good agreement with the ocean results to justify a suspicion that predominating local effects may be largely responsible for this apparent disagreement. *Accordingly, there appear to be good grounds for concluding that, in general, the 24-hour wave of the potential gradient progresses approximately according to universal time over the entire surface of the Earth.*

It is hoped that a study now under way of the interrelations between the potential gradient and the meteorological and other atmospheric-electric elements will also, by the aid of the point of view herein set forth, make it possible to determine in greater detail the relation between local and world-wide effects.

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THE MAGNETIC CHARACTER OF THE YEAR 1922.

The annual review of the "Caractère magnétique de chaque jour" for 1922 has been drawn up in the same manner as the preceeding years. Forty-three observatories contributed to the quarterly reviews, 37 of them having sent complete data.

The following table contains the mean character of each day and each month, the list of "Calm Days" and the days recommended for reproduction.

G. van Dijk.

Dates	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Mean
January	0.2	0.4	0.1	0.2	0.4	0.7	1.1	1.5	1.3	1.1	0.8	0.4	0.2	0.1	0.0	1.2	1.1	0.9	0.8	0.8	0.0	0.0	0.1	1.8	1.5	0.9	0.5	0.2	0.3	0.4	1.3	0.65
February	0.7	0.6	1.4	1.1	0.8	0.9	0.2	1.0	1.2	0.5	0.2	1.2	0.8	1.0	1.4	1.5	0.9	0.5	0.5	0.7	0.8	0.4	0.1	0.1	0.0	0.8	1.0	1.0				0.74
March	1.2	1.0	1.1	0.7	1.5	0.3	0.1	0.1	0.1	1.2	0.8	1.1	1.8	1.9	0.7	0.4	1.1	0.9	1.1	0.9	0.4	0.7	0.1	0.1	1.2	0.5	0.4	0.4	0.8	1.4	1.1	0.79
April	1.0	0.8	0.2	0.0	0.0	0.0	0.1	1.1	1.3	1.2	0.8	1.3	0.8	0.8	0.7	0.6	0.5	0.5	0.1	0.5	1.1	1.6	1.0	1.3	1.1	1.4	1.1	0.6	0.9	0.6		0.75
May	0.2	0.0	0.0	0.3	0.7	0.7	1.3	1.3	1.3	1.1	0.8	0.2	0.2	0.3	0.1	1.4	0.7	0.3	0.6	0.4	1.2	0.9	0.8	0.8	0.8	0.9	0.7	0.4	0.0	0.0	0.0	0.57
June	0.2	1.1	1.1	0.7	1.3	1.0	0.5	0.3	0.3	0.1	0.2	0.7	0.6	0.4	0.0	1.3	1.1	0.9	0.6	0.4	0.5	0.4	0.6	0.1	0.2	0.2	0.7	0.9	1.4	1.4		0.62
July	1.2	0.9	1.0	0.5	0.3	0.4	0.5	0.1	0.2	0.5	0.1	0.0	0.2	1.0	1.0	1.2	0.8	0.8	0.9	0.5	0.1	0.1	0.5	0.8	0.1	1.5	1.4	1.5	1.2	0.9	0.7	0.66
August	0.6	0.3	0.2	0.4	0.9	0.5	0.2	0.3	1.1	1.1	1.6	1.4	1.3	1.3	0.9	0.5	0.1	0.1	0.3	0.6	0.9	0.8	1.2	0.9	0.7	0.8	0.9	0.3	0.8	0.8	0.8	0.71
September	0.5	0.3	0.5	0.4	0.3	0.7	1.4	1.5	1.2	1.1	0.6	0.5	0.9	1.9	1.1	0.4	0.6	0.4	0.2	1.1	1.1	0.2	0.2	0.1	0.3	0.1	1.1	1.1	0.4	1.0		0.69
October	0.2	0.8	1.0	0.9	1.9	1.3	1.2	1.1	0.9	0.7	0.2	0.5	0.5	0.7	0.4	0.1	0.9	0.2	0.1	1.0	0.4	0.0	0.3	0.9	0.9	0.3	0.7	0.5	0.4	0.9	1.6	0.68
November	1.2	1.2	1.2	0.7	0.2	0.0	0.0	0.3	0.4	1.1	0.2	0.1	0.0	0.2	0.6	0.2	0.4	0.1	0.2	0.2	0.6	0.4	0.1	0.2	0.1	0.0	1.0	1.0	1.3	0.9		0.47
December	0.8	0.5	0.1	0.1	0.9	0.9	0.3	0.0	0.4	1.0	0.8	0.4	0.3	1.1	0.9	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.1	0.4	0.8	1.3	0.3	0.3	0.5	0.6	0.2	0.42

Calm Days

January	3,	4,	15,	21,	22.	February	7,	11,	23,	24,	25.	March	7,	8,	9,	23,	24.
April	4,	5,	6,	7,	19.	May	2,	3,	15,	30,	31.	June	10,	11,	15,	24,	25.
July	8,	11,	12,	21,	22.	August	2,	3,	17,	18,	28.	September	2,	22,	23,	24,	26.
October	1,	16,	18,	19,	22.	November	6,	7,	13,	18,	26.	December	3,	8,	16,	22,	23.

Days Recommended for Reproduction

January 24, March 14, May 16, September 14, and October 5.

RESULTS FROM MAGNETIC EAST-WEST PATHS AROUND THE EARTH.

By W. J. Peters.

In the preliminary analysis of the Earth's magnetic field for 1922 by Dr. Louis A. Bauer,[1] it was found desirable to ascertain how an east-west path around the Earth would close that was everywhere throughout its length perpendicular to the direction of the compass needle, or to the horizontal component of the Earth's magnetic field. The considerations involved and the method adopted in constructing eleven such paths are given in these notes, together with the results.

The actual tracing of a path with the required accuracy, exactly magnetic east or exactly magnetic west, on land and over sea, presents many practical difficulties. Periodical time changes all along the path introduce uncertainties. Over land, local disturbances[2] interfere and cities and other constructional culture obstruct the necessary surveying operations, while over the seas, where the only available method at present is to continue the path on a non-magnetic ship, ocean currents and leeway affect the closure sought, not only by precisely the sum of their components perpendicular to the path, but also by shifting the path in regions of critical or steep gradients of the declination, and thereby introducing errors in its direction. The tracing of a path upon isogonic charts of the world is free from these sources of error though subject to others. Local disturbances have been effaced in the smooth isogonics, and time changes are taken care of in the reduction to a common epoch. Cultural detail, ocean currents and winds no longer enter the problem. Hence the plotted closure of a circuit extending exactly magnetic east or west around the Earth depends in this method only upon the systems of magnetization represented by the particular isogonics and upon the accuracy with which data can be scaled from the chart or plotted thereon. Unfortunately, the errors of plotting usually accumulate. It is

[1]Chief Results of a Preliminary Analysis of the Earth's Magnetic Field for 1922, *Terr. Mag.*, vol. 28, 1923, pp. 27-28.

[2]Such a path could be traced overland only step by step as a surveyor runs his lines. A local disturbance, therefore, might not be approached and left gradually, but on the contrary its influence might be confined to one station only. A continuous translation of the needle along the path would be practical only at sea.

possible to compute the closure of the path by a long process involving repeated approximations, provided that the magnetic declination is given as an analytical function of the latitude and longitude. The work entailed, however, renders this method practically useless.

The simplest graphical method is to plot the path on the chart, as consisting of elementary straight lines, from isogonic to isogonic; for then the values of the declination are known *a priori* for each end of the element of path between any two isogonics. The plotting proceeds by laying off the directions or courses which are $\frac{1}{2}(D_1 + D_2) + 90°$, $\frac{1}{2}(D_2 + D_3) + 90°$, etc., D_1, D_2, D_3, etc., being the values of the declination represented by the successive isogonics that are intersected. In this process, a linear change in declination, D, is assumed along the elementary path, Δs, between any two isogonics. The principal objection to this method is the uncertainty in plotting that grows as the number of elementary paths increase. The following method, combining graphical and computing operations *pari passu* as the path proceeds, is the one by which the results stated in Table 1 were obtained.

An element Δs of the path is plotted between two consecutive isogonics, as just described. The longitudes, λ_1 and λ_2, of each end of the element are then scaled from the chart and a table formed from which $\Delta\lambda$ is derived. If on a Mercator projection, Δm represents the meridional part of the elementary right-angled triangle of which $\Delta\lambda$ is the base and Δs the hypothenuse, then for a due magnetic east course of the path

$$\Delta m = -\Delta\lambda \tan \tfrac{1}{2}(D_1 + D_2) \qquad (1)$$

The value of Δm as computed from equation (1) is now plotted with the preliminary scaled value of λ_2 and if the data are consistent, the end of the elementary path as given by the preliminary scaled λ_2 and the computed Δm should fall on the proper isogonic whose value is D_2. In case of failure, the value of $\Delta\lambda$ must be corrected (since the direction or course is fixed by $1/2\ (D_1 + D_2 + 90°)$ to fulfill this condition. The correction can be determined readily in most cases by inspection of the plotting. The next element of the path is then plotted in like manner, starting from the verified or computed point, a similar computation is made, and so on. The final latitude is obtained from a "Table of Meridional Parts," by entering with argument $m_0 + \Sigma\ \Delta m$, in which m_0 is the meridional part corresponding to the initial latitude.

Mercator's projection, upon which the world isogonics are often drawn, is particularly adapted to the method, since the variable latitude scale is not required, the longitudes can be scaled with a scale of equal parts and the mercatorial azimuth is the mean of the forward and the back azimuths, that is, the mean value of two consecutive isogonics plus 90° eastwardly. Moreover, the errors in scaling longitudes are not cumulative; on the contrary, they compensate to a certain extent, for if any one value of the longitudes is in error, the adjacent values of $\Delta\lambda$ will be in error by precisely the same amount, but each with a sign opposite to the other.

The accuracy of the method could be increased by constructing charts on a very large scale, with very small intervals between the isogonics, especially in regions where the method is weak. It is not necessary always to see that the end of every element of the computed path falls on its proper isogonic. Where the isogonics are distributed uniformly and close together, longer intervals may safely be taken between the verifications.

The method is fairly quick and satisfactory. Its weakness occurs, as in any graphic method, when the path crosses the isogonics at very acute angles. In these cases, as well as in some others where the change in declination along the current path evidently is not linear, it is advisable to plot a curve on cross-section paper of large scale. The abscissae in these plottings are tentative longitudes scaled from the chart after extending the preliminary plotting of individual elements of the path far enough for the purpose and the ordinates are plotted proportional to the tangents of the corresponding isogonics. A curve so constructed will show what corrections will improve the tentative longitudes, or in the case of a maximum or minimum in the curve, the mean ordinate corresponding to any difference of longtitude is determined from the area inclosed, which can be measured very quickly with a planimeter. If the improved longitudes or the mean ordinate fail to throw the positions of the end of each element of the path upon its proper isogonic, the curve is plotted again with corrected data. It was seldom necessary to plot the curve twice in deducing the results given in Table 1.

Another manner of dealing with these critical cases is to sketch on the chart as many intermediate isogonics as may be necessary to permit of the assumption of linear change without material error. These interpolated isogonics must conform to the system or systems of magnetization as depicted by the original isogonics, otherwise

there would be an effect in the result sought, not attributable to the original systems. This manner of dealing with critical cases requires a more experienced and skillful drawing than does the plotting on cross-section paper.

Aside from any other consideration, scalings, and plotting are more accurate on charts of large scale. The results of Table 1 were obtained from the British Admiralty Charts 3775, 3776, and 3777, but in some regions, when the title interfered, chart 2598 was used; these charts are for the epoch 1922. The isogonics are spaced at one degree intervals over the sea and generally at 5 degree intervals over the land. The scale of the three large sheets, which are contiguous, is 5 degrees of longitude to one inch, while the small sheet covering the whole world has 60 degrees of longitude to 5½ inches.

Eleven paths are given in Table 1, all starting from the meridian of Greenwich. Five of these, *a*, *d*, *f*, *h*, and *k* were obtained by two computers, Mr. C. R. Duvall and the author, working independently, but using practically the same method of plotting *pari passu* with computing. The greatest difference in their independent determinations of the lack of closure is less than 18 statute miles. The first column designates each path by letter, the second and third show respectively the latitude and the declination, *D*, of the starting point, while the length of the path, *s*, is given in the fourth column. The distance, *d*, between the starting

TABLE 1.—*Summary for paths at right angles to the magnetic meridian.*

Reference	Latitude of starting point	D (Decl'n)	s (Length of Path)	d Mer. distance bet. start and end	Direction of d	p= (d cos D)	arc tan $\frac{d \cos D}{s}$
	° ′	°	*statute mi.*	*statute mi.*		*statute mi*	′
a	50 00 N	13.6W	180 x 10^2	33.9 (mean)	N	32.9	6 W
b	40 00 N	11.8W	205 x 10^2	36.0	S	35.2	6 E
c	30 00 N	11.0W	218 x 10^2	34.1	S	33.5	5 E
d	20 00 N	11.0W	242 x 10^2	58.7 (mean)	S	57.6	8 E
e	10 00 N	12.2W	248 x 10^2	12.8	S	12.5	2 E
f	Equator	16.0W	250 x 10^2	31.3 (mean)	N	30.1	4 W
g	10 00 S	20.0W	249 x 10^2	2.0	S	1.9	0
h	20 00 S	24.75W	240 x 10^2	21.5 (mean)	N	19.5	3 W
i	30 00 S	28.0W	230 x 10^2	79.6	N	70.3	10 W
j	40 00 S	28.2W	226 x 10^2	116.1	N	102.3	15 W
k	50 00 S	25.4W	205 x 10^2	119.3 (mean)	N	107.8	18 W
		Mean of a, b, c, d, e		....	S	21.2	3.0 E
		Mean of g, h, i, j, k.		....	N	59.6	9.2 W

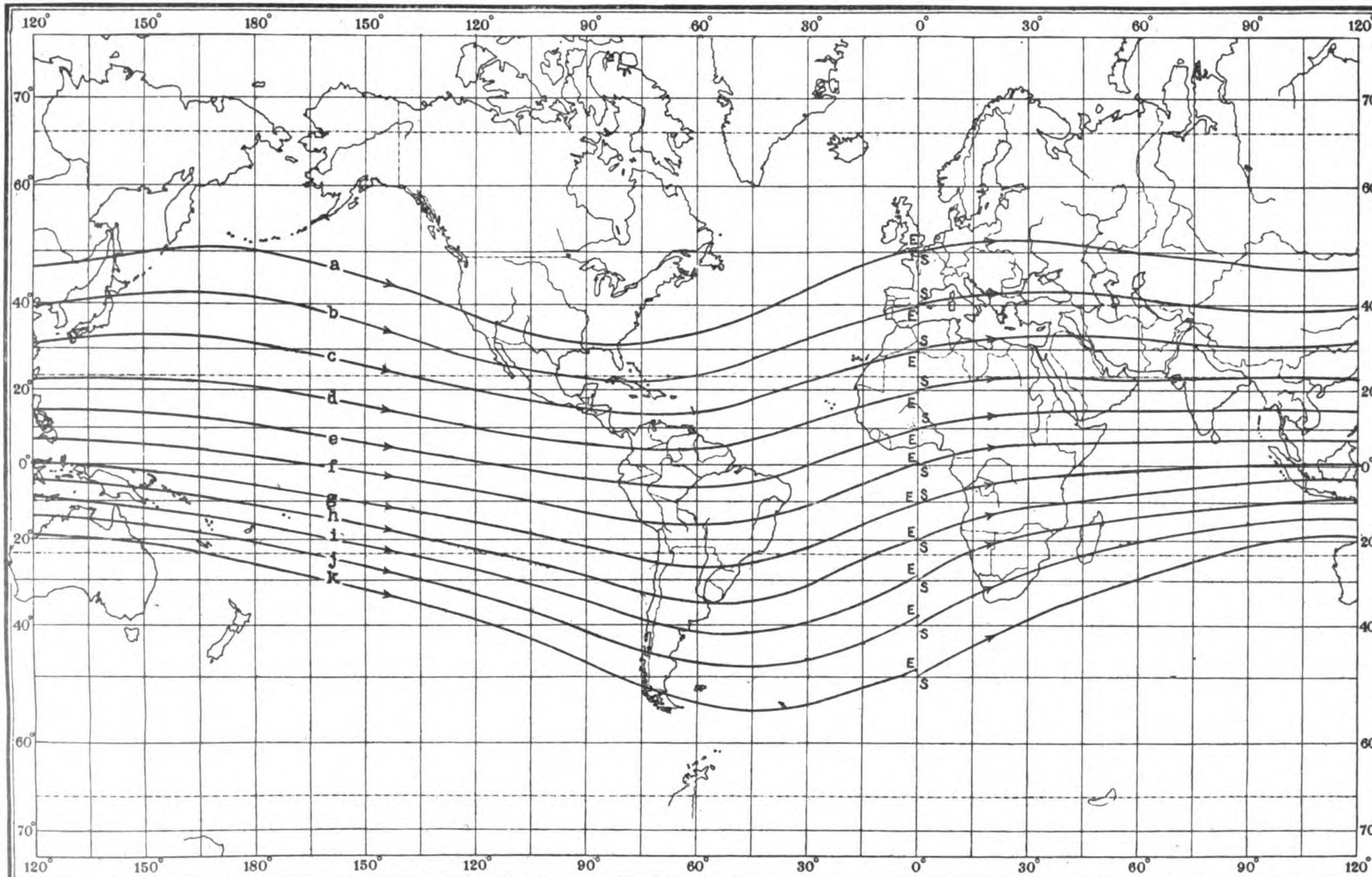

FIG. 1.—MAGNETIC EAST-WEST PATHS FOR 1922.

point, S, and the intersection, or ending point, E, of each completed path with the meridian of the starting point, i. e., of Greenwich, is found in the fifth column and its direction from the starting point (due north or due south) is given in the sixth column. The shortest distance, p, between the path at starting and the closing path is perpendicular to the path and is given by the expression $d \cos D$, which is tabulated in the seventh column. The eighth column gives the average angle east or west of magnetic north that the direction of the horizontal component of the Earth's field must have been deflected from the direction a magnetic potential system would give it, in order to produce the total error or lack of closure.

The eleven paths are drawn on the accompanying small map of the world (Fig. 1) and are designated by reference letters according to Table 1. The means of p and arc tan $\frac{d \cos D}{s}$ for paths a, b, c, d, and e are taken as approximate average values for the zone included between parallels 5° north and 50° north, while the approximate average values for the corresponding southern zone are obtained from paths g, h, i, j *and* k. These means for arc tan $\frac{d \cos D}{s}$, as given in the last column of Table 1, viz., 3′ east for northern latitudes and 9′ west for southern latitudes, are in fair agreement with conclusions given by Dr. Bauer,[1] as the result of the indicated existence of a non-potential system, which, as a first approximation, contributes about 3 per cent to the magnetic force observed on the Earth's surface.

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[1] *Terr. Mag.*, vol. 28, 1923, p. 12, § 14.

GENERAL DESCRIPTION OF THE EARTH-CURRENT MEASURING SYSTEM AT THE WATHEROO MAGNETIC OBSERVATORY.

By O. H. Gish.

Abstract.—The paper consists essentially of two parts, the first being an analysis setting forth the general requirements for the determination of the earth-current density vector, and the second a description of the outstanding features of the system installed at the Watheroo Magnetic Observatory (in Western Australia) for measuring the potential gradient of earth currents.

General requirements.—A complete description of earth currents requires a knowledge of the distribution of, (1) the earth resistivity, and (2) the earth-current potential. A method suitable for determining the former is indicated. The major portion of the analysis, however, deals with the potential gradient. It is first indicated that a "potential survey" should be made in the vicinity of earth-current lines in order to locate and measure any discontinuities that may exist in the potential field. General methods of approximately determining the potential gradient at a point are then given. The relations for resolving and combining earth-current potential measurements are developed in such a manner as to include the less favorable case where the lines are not at right angles to each other.

The *earth-current lines at Watheroo* are so arranged that the earthed points determine a right angle, one limb of which extends due east and the other due north from the vertex. The point at the vertex is used as a common point of reference for the potentials of the other points. Two other points on each limb are situated, at present, 1.6 km. and 3.2 km. distant, respectively, from the common point. The potential difference between the common point and the nearer point on each branch can be alternately recorded by means of overhead and underground systems, and thus a close comparison of the relative virtue of these two types of line may be made. Only overhead lines connect with the farther point on each line. The overhead lines possess no features of special interest. The underground lines consist of leaded rubber-covered copper conductors in bituminized fiber conduit, placed at a depth of 46 cm. below the earth's surface. For other details, reference may be made to the complete article.

An approximate quantitative description, based on direct observations, of the system of electric currents flowing in the Earth's crust must, aside from its intrinsic value, be of importance in corroborating existing theories of terrestrial electromagnetic systems or in necessitating modification or amplification of such theories. In particular the theory of the solar and lunar diurnal magnetic variations originated by Balfour Stewart[1] and Schuster[2] and later developed by S. Chapman[3] indicate rather definite general systems of induced currents in the Earth's crust. Futhermore, a comparison of the vector diagrams of the diurnal variation of the horizontal magnetic intensity with such diagrams for the variation in the potential gradient of the earth currents, as were constructed by Weinstein[4] from the Berlin data and by Bauer[5] from the ob-

[1] Balfour-Stewart, *Ency. Brit.*, 1882, 9th ed., vol. 16, pp. 159-184, article "Terrestrial Magnetism."

[2] A. Schuster, *Phil. Trans. R. Soc.*, A, 1889, vol. 180, pp. 467-518; A, 1908, vol. 208, pp. 163-204.

[3] S. Chapman, *Dict. Applied Phys.*, vol. 2, pp. 551-561, where references to the principal original papers on the subject may be found.

[4] B. Weinstein, Tafeln, Die Erdströme im deutschen Reichstelegraphengebiet und ihr Zusammenhang mit den erdmagnetischen Erscheinungen; Braunschweig, 1900.

[5] L. A. Bauer, *Terr. Mag.*, vol. 27, 1922, pp. 1-30.

servations at the Observatorio del Ebro, shows similarities which suggest a relationship somewhat like that indicated by the theory mentioned above.[6] Such comparisons can be scarcely more than qualitative owing to the fact that up to the present time the measurements reported, even when ignoring spurious effects at the electrodes and other systematic errors, yield only the potential gradient. Other cases might be cited where earth-current measurements may serve as a check on theory or when used conjointly with theory new facts may be determined, but to do so would be beyond the scope of the present paper. It is desired rather to point out here that in the light of our present knowledge of correlated branches of cosmical physics, earth-current phenomena should not present such baffling complexities, nor with the improved instrumental equipment now available should the difficulties of reliable measurement prove as discouraging, as in the years when interest in this subject was at a maximum. It is accordingly very opportune that interest be renewed and that continuous quantitative measurements of the earth-current vector be made at a number of places well distributed over the Earth's surface.

GENERAL REQUIREMENTS IN EARTH-CURRENT MEASUREMENTS.

In order to completely determine I, the current density vector, it is necessary to know both k, the specific conductivity, and $\mathbf{G}$, the potential gradient. Since

$$\mathbf{I} = k\mathbf{G} \tag{1}$$

Determination of the specific conductivity of the Earth. To determine k, the conductivity, or $1/k$, the resistivity of the Earth in the region where the earth currents are to be measured, use may be made of a method which has been outlined by Wenner.[7] This method with some modification has also been used by McCollum in making electrolysis surveys.[8] It should be possible, as has been pointed out by Wenner to obtain by this method not alone the lateral distribution but also to a certain approximation the distribution of conductivity with depth. The major part of such a survey could doubtless be made once for all but minor surveys would probably be made at different seasons of the year

[6]It should be mentioned here that Chapman and Whitehead have made a careful comparison between the earth-current potential gradient as computed from the theory and the observed values published by Weinstein; they find qualitative agreement (see *Trans. Phil. Soc., Cambridge*, vol. 22, No. 25, 1922, pp. 479-482).

[7]F. WENNER, *U. S. Bureau of Standards Scientific Paper*, No. 258.

[8]BURTON MCCOLLUM, *Elect. Ry. Journ.*, Nov. 5, 1921, pp. 809-813.

or at other intervals. Information such as may be in this way obtained should also be of interest entirely apart from earth-current measurements.

Determination of the earth-current potential gradient. If V, the earth-current potential, is a scalar point function which is analytical in the region of space where measurements are to be made, then the rate of change of V along any line s is:

$$\frac{\partial V}{\partial s}=\frac{\partial V}{\partial x}\cdot\frac{dx}{ds}+\frac{\partial V}{\partial y}\cdot\frac{dy}{ds}+\frac{\partial V}{\partial z}\cdot\frac{dz}{ds}. \tag{2}$$

When x, y and z are the rectangular coordinates of a point on the line element (ds), and α, β and γ are the direction angles between ds and the X, Y and Z axes respectively, then

$$\frac{dx}{ds}=\cos\alpha;\ \frac{dy}{ds}=\cos\beta;\ \frac{dz}{ds}=\cos\gamma. \tag{3}$$

It is entirely probable that V is not in all cases an analytical function of the space coordinates. For example, polarization, or electrochemical effects, may exist across planes where two different geological formations meet thus giving rise to discontinuities. Consequently unless the structure in the region where earth currents are to be studied is very homogeneous it would seem advisable to make a survey of the earth potentials and thus determine the magnitude of such discontinuities as occur. Equipment and method similar to that developed by Schlumberger[9] and also used by Kelly[10] would likely be suitable for this purpose.

In general, a direction will be found in which the rate of change expressed by (2) at a given point, is a maximum. This maximum rate is thus a vector, the gradient (**G**) of the potential at the point. The analytical expression for this vector is:

$$\mathbf{G}=-\left(\mathbf{i}\frac{\partial V}{\partial x}+\mathbf{j}\frac{\partial V}{\partial y}+\mathbf{k}\frac{\partial V}{\partial z}\right) \tag{4}$$

when x, y and z are rectangular coordinates. Its magnitude may be determined, if $\frac{\partial V}{\partial x}$, $\frac{\partial V}{\partial y}$ and $\frac{\partial V}{\partial z}$ are known, from the relation

$$G=\sqrt{\left(\frac{\partial V}{\partial x}\right)^2+\left(\frac{\partial V}{\partial y}\right)^2+\left(\frac{\partial V}{\partial z}\right)^2} \tag{5}$$

[9] C. SCHLUMBERGER, "Étude sur la Prospection Électrique de Sous-Sol." (1920 Gauthier-Villars, Paris.

[10] SHERWIN F. KELLY, *Eng. and Min. Jour.*, Oct. 7, 1922, pp. 623-628; Oct. 17, 1922, pp. 673-676.

Its direction cosines relative to the X, Y, and Z axes are respectively:

$$-\frac{\partial V}{\partial x}\bigg/ G\ ,\ -\frac{\partial V}{\partial y}\bigg/ G\text{ , and }-\frac{\partial V}{\partial z}\bigg/ G \qquad (6)$$

If the differences of potential between points on each of three mutually perpendicular lines and their common point, is found, and the distance of each of the points from the common point determined, then an approximate value of the gradient at the latter may be computed from the data thus obtained, provided the distances are so small that any lack of uniformity in the field of the earth-current potentials can be neglected. When the non-uniformity is great the foregoing arrangement may be modified by providing additional earthed points on each line so as to make possible a representation of the variation of potential as a function of the distance from the common point in each case. From such functions, determined either graphically or analytically, the values of the potential gradient components at the common point may then be approximately determined.

A rectangular arrangement of lines, somewhat as outlined above, one in a due east-west direction, another in the due north-south and a third, if employed, in the direction of the vertical downwards, is apparently the most favorable as regards reduction of the data.

In some cases, however, it is not feasable to arrange the lines at right angles. In such cases, for purpose of correlation, for example, with the magnetic elements, the observed rates of change of potential in the direction of the respective lines at the common point, call these $\frac{\partial V}{\partial s_1}$ $\frac{\partial V}{\partial s_1}$ and $\frac{\partial V}{\partial s_3}$, must be resolved into components in the direction of the axes of such a rectangular system as was indicated above. Because of evidence in the literature of confusion on this matter, this case will be considered. This may be done by employing equations (2) and (3) which give the following expression for the space rate of change of potential along each line.

$$\frac{\partial V}{\partial s_1} = \frac{\partial V}{\partial x}\cos\alpha_1 + \frac{\partial V}{\partial y}\cos\beta_1 + \frac{\partial V}{\partial z}\cos\gamma_1$$

$$\frac{\partial V}{\partial s_2} = \frac{\partial V}{\partial x}\cos\alpha_2 + \frac{\partial V}{\partial y}\cos\beta_2 + \frac{\partial V}{\partial z}\cos\gamma_2 \qquad (7)$$

and if desired

$$\frac{\partial V}{\partial s_3} = \frac{\partial V}{\partial x}\cos\alpha_3 + \frac{\partial V}{\partial y}\cos\beta_3 + \frac{\partial V}{\partial z}\cos\gamma_3$$

where α_1, and α_2 and α_3 are the direction angles which the lines s_1, s_2 and s_3 respectively make with the X-axis of the rectangular system and the other angles in the same order are the direction angles relative to the other axes.

From equations (7) we can then obtain

$$\frac{\partial V}{\partial x} = + \frac{\begin{vmatrix} \frac{\partial V}{\partial s_1}, & \frac{\partial V}{\partial s_2}, & \frac{\partial V}{\partial s_3} \\ \cos\beta_1, & \cos\beta_2, & \cos\beta_3 \\ \cos\gamma_1, & \cos\gamma_2, & \cos\gamma_3 \end{vmatrix}}{\begin{vmatrix} \cos\alpha_1, & \cos\alpha_2, & \cos\alpha_3 \\ \cos\beta_1, & \cos\beta_2, & \cos\beta_3 \\ \cos\gamma_1, & \cos\gamma_2, & \cos\gamma_3 \end{vmatrix}}$$

$$\frac{\partial V}{\partial y} = - \frac{\begin{vmatrix} \frac{\partial V}{\partial s_1}, & \frac{\partial V}{\partial s_2}, & \frac{\partial V}{\partial s_3} \\ \cos\alpha_1, & \cos\alpha_2, & \cos\alpha_3 \\ \cos\gamma_1, & \cos\gamma_2, & \cos\gamma_3 \end{vmatrix}}{\begin{vmatrix} \cos\alpha_1, & \cos\alpha_2, & \cos\alpha_3 \\ \cos\beta_1, & \cos\beta_2, & \cos\beta_3 \\ \cos\gamma_1, & \cos\gamma_2, & \cos\gamma_3 \end{vmatrix}} \tag{8}$$

with a similar expression for $\frac{\partial V}{\partial z}$. A simple case of practical importance is that where the s_1 and s_2 lines lie in a horizontal plane and the s_3 line is along the vertical. The direction angles will then be α_1, the azimuth of the s_1 line; α_2 that of the s_2 line; $\beta_1 = 90° - \alpha_1$; $\beta_2 = 90° - \alpha_2$; $\alpha_3 = \beta_3 = \gamma_1 = \gamma_2 = 90°$; $\gamma_3 = 0°$. Hence from (8)

$$\frac{\partial V}{\partial x} = \frac{\frac{\partial V}{\partial s_1}\sin\alpha_2 - \frac{\partial V}{\partial s_2}\sin\alpha_1}{\sin(\alpha_2 - \alpha_1)}$$

$$\frac{\partial V}{\partial y} = \frac{\frac{\partial V}{\partial s_2}\cos\alpha_1 - \frac{\partial V}{\partial s_1}\cos\alpha_2}{\sin(\alpha_2 - \alpha_1)} \tag{9}$$

and of course $\frac{\partial V}{\partial s_3} \equiv \frac{\partial V}{\partial z}$. The magnitude of the potential gradient and its azimuth could also be expressed directly in terms of the observed quantities and the azimuths of the lines but no advantage is to be gained by doing so in this case.

INSTALLATION AND EQUIPMENT AT WATHEROO MAGNETIC OBSERVATORY.

Upon recommendation of the Director of the Department of Terrestrial Magnetism, the Carnegie Institution of Washington made provision in 1922 for installing at its observatory at Watheroo, Western Australia, lines and equipment for the continuous recording of earth currents. Although vesting-orders generously issued by the Australian government made available for this work two ten-mile strips of land two rods wide adjacent to the observatory site, yet the entire extent of these has not been used in this initial system. It is a general belief that lines whose lengths are expressed in tens or hundreds of kilometers will yield data in which the relative weight of spurious electrode effects, such as enter to some extent in all earth-current potential measurements, is small as compared with that of much shorter lines.

This belief is based on the assumption that, while the earth-current potential difference increases with the distance between electrodes, the electrode and other spurious effects are neither larger nor of more frequent occurrence on long than on short lines. The latter part of this assumption can, however, scarcely be justified since meteorological and geological, as well as some other factors, are likely to be not only greater but also subject to more frequent change, the more widely separated are the earthed points. Furthermore, the virtues of the longer lines have weighted against them the greater cost of installation and upkeep and the increased difficulty of special tests and control observations.

One cannot determine from the published data to what extent these various disadvantages counteract the advantages, but there is evidence of such an effect. That earth-current lines as short as one kilometer in length may give usable data, is perhaps shown most significantly by a comparison of the results obtained by Bauer[11] in his study of the Observatorio del Ebro data obtained on lines of lengths 1.28 and 1.42 kilometers with those Weinstein[12] obtained from data furnished by lines 120 and 262 kilometers long.

It, therefore, seemed sufficiently probable that lines a few kilometers in length would, with proper control, give such satisfactory data as to justify their trial at Watheroo.

The following description will indicate the general features of the scheme and equipment and will show the manner in which it is attempted to meet the general requirements outlined in the first part of this paper. Thus far only the measurement of the potential

[11]See footnote 5. [12]See footnote 4.

gradient is provided for. The method and equipment for resistivity surveys will be developed later.

Design of earth-current lines at Watheroo. Fig. 1 shows a plan of the Observatory Site and the layout of the earth-current lines. These lines constitute a rectangular system with a common earthed point at *O*, and two points (*M*, *N* and *P*, *Q* respectively) on each line, distributed at intervals of one mile (about 1.6 km). The line *OMN* extends due east and *OPQ* due north from the south-

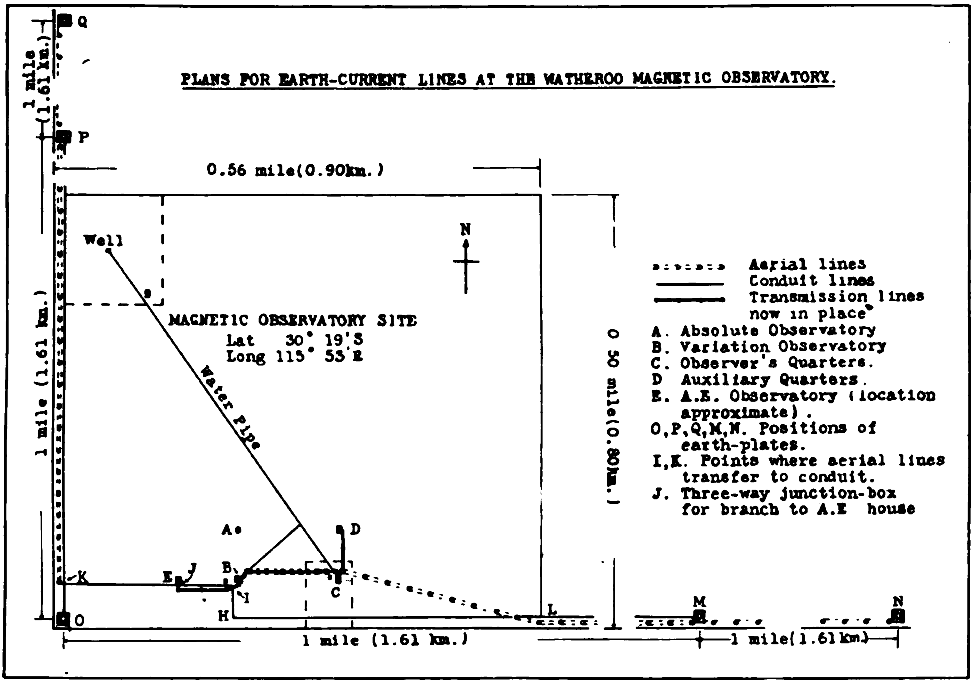


FIG. 1.

west corner of the Site. The extra point provided in each branch is intended to make possible a better approximation of the potential gradient, in the event of much departure from uniformity in the potential field, but it should also be of service in detecting spurious variations in the electrode potentials. This is one of a number of experimental features of this installation, and whether it shall later be discontinued or extended will be determined by the preliminary results that are obtained.

The type of line which in many ways would seem to be best suited for this particular location is one in which leaded rubber-covered copper conductor is laid in an insulating conduit. Though

this type of installation has a number of obvious advantages over an aerial line the cost of installation is considerably greater, and when in addition to this the fact was noted that apparently no close comparison of overhead and underground lines have thus far been made, it seemed advisable that at the outset in our earth-current studies, lines designed to make such comparison should be installed. These may later be of value not only for guidance in future installation but should also aid in more correctly appraising the results previously obtained by other investigators. It is for this reason that two parallel lines one underground and the other overhead are provided in order to connect the points P and M respectively with O. The general disposition of the lines may be seen from Figs. 1 and 2 where the aerial lines are represented by a series of small circles and dashes, while the subterranean lines are indicated by a heavy solid line. The points N and Q may be connected with O only by overhead lines. Mercury switches operated by eight-day clocks are placed at M and P, so that the aerial and the subterranean lines which terminate at these points will alternately be connected to the earth-plates here. This provision is made in order that possible spurious effects arising on one line shall not affect the record obtained on the other.

It will be noticed that between the points K and I no aerial lines are shown. The conductors pass into the conduit at these points in order to obviate distortion of the atmospheric-electric field in the vicinity of the Atmospheric-electric and Earth-current Instrument House at E.

The *subterranean lines* consist of cable in bituminized fiber conduit placed at a depth of 18 inches (46 cm.) below surface and provided at intervals of 400 feet (120 m.) with junction boxes of the same material. Some aspects of these lines can best be obtained by a glance at Figs. 3 and 4 which are views supplied by Dr. G. R. Wait, who as Observer-in-Charge of the Watheroo Observatory, supervised this installation. The level character of the terrain, and the friable condition of the soil are favorable to this type of installation. The trench was readily made with a simple trenching device. At the points O, P, Q, N and M of Fig. 1, special concrete terminal boxes are provided and at K, J, I and H junction boxes of concrete, similar to the terminal boxes have been installed. The cable which is used is No. 14 Brown and Sharpe 1.63 mm. diameter copper wire with rubber insulation and an outer sheath of lead. The splices, or joints, in this cable were carefully insulated and provided with lead sheath so as to give a complete outer protection

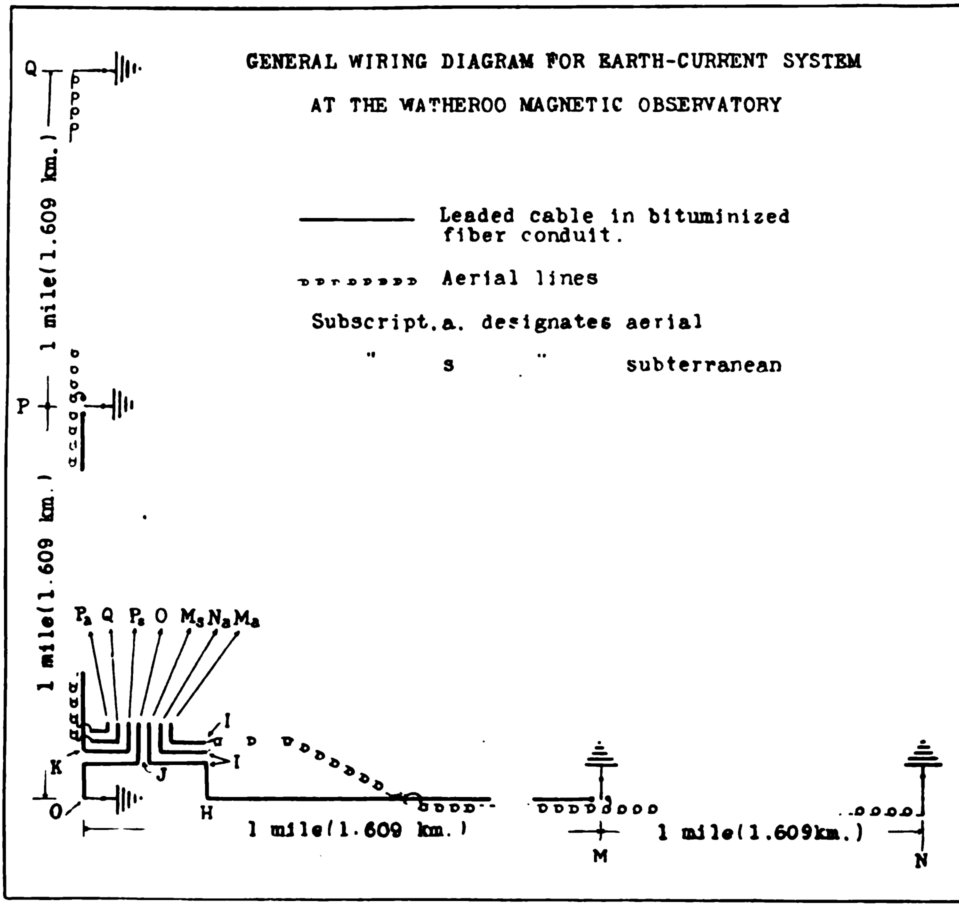


FIG. 2.

FIG. 3.—Laying Conduit on West-East Earth-Current Line. A Junction Box is just being placed.

FIG. 4.—Drawing Cable into the Conduit on West-East Earth-Current Line.

of lead to the insulating material of the cable. The lines all converge to E where the recording instrument is installed.

The *overhead lines* have only a few features of special interest. The conductor is a double braid rubber-covered No. 14, Brown and Sharpe, copper wire. The insulators are such as are used on light 5,000 volt transmission lines. At the points K and I where these overhead lines pass into the conduit, and at M, N, P and Q where the lines go into the terminal boxes before being connected to the electrode, the conductors make connection with the leaded cable in

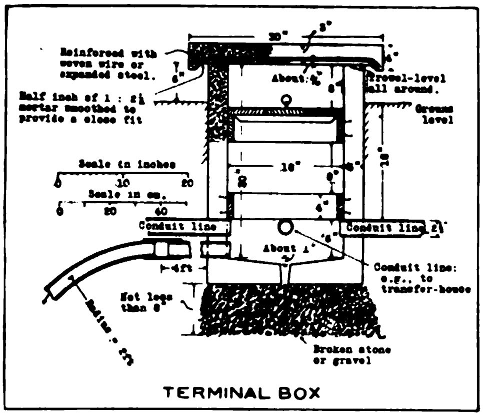


FIG. 5.

a small transfer box placed near the top of a pole. At these points lightning arresters and fuses are also provided. The leaded cable going from the transfer box to the terminal or outlet boxes, as the case may be, is placed in the same kind of conduit as is used on the underground lines.

The *terminal boxes* which were placed at the points O, M, N, P and Q are designed to accommodate switches by means of which the lines may be disconnected from the electrodes when tests for line insulation or special electrode tests are in progress. They will also accommodate small instruments, such as thermographs, or special apparatus, as for example, the automatic switches which, as has already been mentioned, are placed at P and M. The sketch in Fig. 5 shows the details of such a terminal box. Between the removable concrete top and a wooden inner cover is an eight inch air space which serves primarily as an insulator to lessen the temperature variation in the lower part of the box. About a foot below the inner cover, cleats are provided to which the switches may be attached, or which may support a shelf for the instruments.

Electrodes. The greatest obstacle in the way of quantitative measurements of earth currents is the spurious effects which arise at the electrodes. Thus two electrodes made from a conducting solid even though every precaution be taken to make them chemically and physically identical, will when placed in a medium, such as water or soil, usually show differences of potential which are too great to be neglected in earth-current measurements.

Laboratory experiments made at the Department of Terrestrial Magnetism show, furthermore, that these differences of potential vary over wide limits even when temperature and moisture conditions in the soil are fairly constant. Part of this effect apparently has its seat in a thin film at the surface of the electrodes as may be shown if one of a pair of electrodes immersed in water is subjected to slight friction with a glass rod. Part arises from changes in the concentration of the solutions surrounding the electrode, thus for example, the addition of water to the soil about one electrode will materially change its potential relative to one whose environment has remained unchanged. These changes in potential range from a few hundredths to as much as a few tenths of a volt. Comparisons between a large number of metals indicate that lead, iron, and possibly cadmium are distinctly superior for this purpose as compared with other metals that have been tried. The reversible electrodes, such as metallic copper dipping into copper-sulphate solution or zinc in a solution of zinc-sulphate, the solution making contact with the soil through a porous membrane, are probably less subject to spurious effects and have greater constancy, when properly maintained, than have metallic electrodes, but certain difficulties arise in their use such for example as the leaching of some solution into the soil with the consequence that specific conductivity of the earth in the vicinity of the lines changes. This in a permanent installation may in time materially distort the potential field which is to be measured. Those reversible electrodes which have been considered are also rather sensitive to temperature changes. If electrodes of metallic zinc are used, temperature and pressure effects must also be guarded against as was clearly shown by the investigations of Mauchly,[13] and very likely a similar statement would apply to other metallic electrodes. The electrode therefore presents a problem demanding further serious study. It is hoped that experiments now in progress, or in prospect, will in time lead to a design of electrode which will meet the rather severe demands in earth-current measurements. A semi-arid region like that at

[13] S. J. Mauchly, *Terr. Mag.*, vol. 23, 1918, pp. 73-91.

Watheroo is extraordinarily unfavorable for proper electrode installations on account of the large variation in soil solution that may occur.

For the present, however, *only temporary electrodes* have been decided upon for use there. These electrodes consist of coils made from remnants of the leaded cable that was used for the subterranean lines. At one end of this cable sufficient insulation was removed so that the lead sheath could be pressed into good electrical

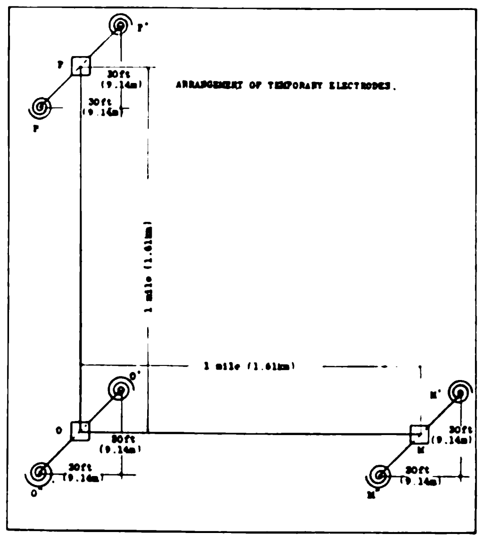


FIG. 6.

contact with the copper conductor and closed by soldering, thus leaving no copper surface exposed. After making a flat spiral of about four inch (10 cm.) pitch and approximately four feet (1.2 m.) in diameter, the remainder of the lead sheath was carefully removed, in a manner so as to avoid injuring the insulation, until a length of insulated cable without lead sheath of sufficient length to lead from the point where the electrode is to be installed to the terminal box, was obtained. These electrodes were then installed at such a position relative to the terminal boxes so as not to be disturbed when the permanent electrodes are installed and in this way admit of more carefully comparing the records obtained from the temporary electrodes, with such as are later obtained from permanent electrodes. They were placed approximately as shown in Fig. 6. The depth below the surface should be sufficient to avoid effects arising from diurnal temperature changes, consequently they were placed between two and three feet (0.6 to 0.9 m.) below

the surface and drainage conditions in the immediate vicinity of all electrodes were made as nearly identical as possible. For this purpose a small mound of earth was made about twice the electrode diameter, over the electrode, which should tend to cause general drainage from it and thus lessen the chances of large variations in the soil solutions making direct contact with the electrodes.

Since the galvanometer of the recorder is designed, for an external resistance of approximately 400 ohms, an endeavor was made to so install the electrodes as to not greatly exceed that value. To this end the following consideration is helpful.

The *resistance of earth-current measuring circuits* consists of that of the lines and instruments, the so-called "contact resistance" of the electrodes, and the resistance along the conducting path through the earth between the electrodes. The major part of the total circuit resistance on lines more than 100 feet in length, leaving out of consideration that of the measuring instruments, usually comes from what we choose to call the *"contact resistance" of the electrodes.* This term being understood to cover resistance which may depend not only upon the effective contact surface of the electrode but also upon the conductivity of the soil in the region more immediately surrounding the electrode. The former is normally the chief factor so that an increase in the effective contact surface of the electrode will decrease the "contact resistance." This can be done in several ways without necessarily increasing the actual electrode surface. One is to firmly pack the soil about the electrodes, another is to introduce several small electrodes connected in parallel in the region, but these must not be placed too close together. If the spirals which have here been used for temporary electrodes are expanded, that is the distance between turns increased, this will also increase the effective surface.

A knowledge of the "contact resistance" of each electrode may throw light on other electrode characteristics, especially such as are associated with spurious effects, and consequently it seems worth while to install electrodes in such a manner that this knowledge may be obtained at intervals. Comparatively simple measurements will yield these data provided two electrodes are installed in the region of each terminal. The position and separation indicated in Fig. 6 is adapted to this purpose. A separate and well insulated conductor leads from each of the two electrodes to the respective terminal boxes where the connections with the line for measuring the desired resistance of the electrodes can be made at any time.

The following consideration will show the method of observation and of computing the individual "contact resistances." It may also be helpful in that a method of procedure is indicated for installing electrodes so as to not exceed a specified resistance. Thus suppose that two electrodes whose unknown resistances are x and v are placed, say, at O' and O'', respectively, near one terminal, and two others having unknown resistances y and w at M' and M'', respectively, near the other terminal. These should be placed 15 to 30 feet (4.5 to 9 m.) apart in order to satisfy the relations which follow. Also let z represent the unknown resistance of the metallic conductors connecting the two points, combined with that of the major part of the conducting path through the earth between the terminals. Then from resistance measurements, first with electrodes O' and M' connected with the line, a value, say R_1, will be found; while with M'' replacing M', R_2 is obtained and with O' still connected at one end and both M' and M'' in multiple at the other, the value R_3 may be measured. The observer now has sufficient data to determine the "contact resistance" of both electrodes, M' and M''. These measurements could thus far all be made at one end of the line. A portable type Wheatstone bridge may be used for rough measurements. Errors due to polarization may be reduced by avoiding long contact on the battery circuit and by using a reversing switch. If now the values of x and v are desired, it will be necessary, after connecting M' instead of M'' to the lines, to go to the end where O' and O'' are located, and after putting O'' instead of O' in the circuit, measure the resistance, say R_4, and finally after determining the resistance R_5, which obtains when O' and O'' are connected in parallel at their end of the line and M' at the other, the data will be sufficient to completely determine the "contact resistance" of each of the four earthed plates or electrodes, and also, if desired, that of the combined circuit consisting of copper conductor and earth.

The relations existing between these values would then be;

$$\left.\begin{aligned} R_1 &= x + z + y \\ R_1 &= x + z + w \\ R_3 &= x + z + \frac{y\,w}{y + w} \\ R_4 &= v + z + y \\ R_5 &= \frac{x\,v}{x + v} + z + y \end{aligned}\right\} \qquad (10)$$

From which we find that;

$$x = R_1 - R_5 + \sqrt{(R_1 - R_5)(R_4 - R_5)} \qquad (11a)$$
$$v = R_4 - R_5 + \sqrt{(R_1 - R_5)(R_4 - R_5)} \qquad (11b)$$
$$y = R_1 - R_3 + \sqrt{(R_1 - R_3)(R_2 - R_3)} \qquad (11c)$$
$$w = R_2 - R_3 + \sqrt{(R_1 - R_3)(R_2 - R_3)} \qquad (11d)$$
$$z = R_1 - (x + y) \qquad (11e)$$

The positive sign of the radical should always be used.

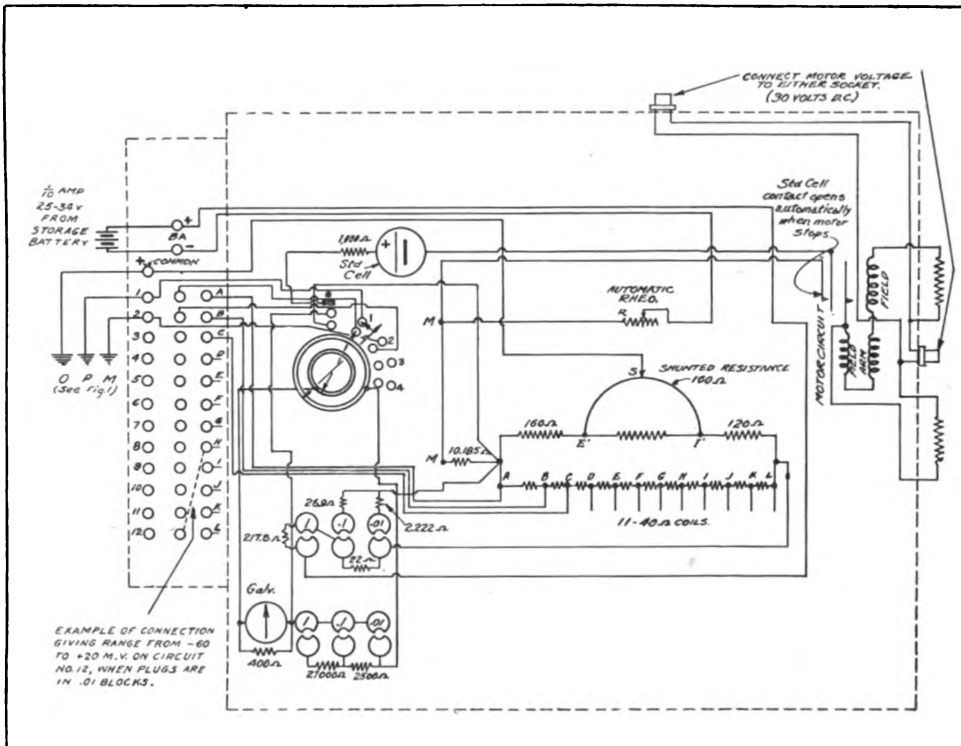
When electrodes are being installed the practical procedure would be: First place a very temporary electrode at some point M', and another at O', Fig. 6, after which install an electrode at O'' in such a manner as is believed should fulfill the specified requirements. Now measure the resistance with the electrode at O'' and that at M' connected to the line $O\ M$, call this R_1. Then measure that of the circuit when O' is substituted for O'', call it R_2, and finally connecting O' and O'' in multiple to the circuit, find the resistance, say R_3. The "contact resistance" of O' can now be computed from equation (11-c) above. If this is much too great try devices for lessening it, one of which is to expand the spiral simply by increasing the distance between turns. It is not necessary to completely bury the electrode O'' before making the first trial, in which case, however, some allowance should be made for the decrease that would result to the resistance from filling the trench and thoroughly tamping the soil. After an attempt is made to decrease the resistance of O'', a measurement of the resistance with it in series with the line and M' and the earth-return, will show what change has resulted. With this procedure it should be possible to install electrodes so that their resistances are of a prescribed order of magnitude.

The *recording equipment.* In the first part of this paper it was shown that the distribution of potential which must in general be found in order to obtain an adequate description of the earth-current vector in a given region, may be such as to require the approximately continuous recording of a number of potential differences. An apparatus which offers promise of being well suited to meet this demand is the Leeds and Northrup multiple-point recorder, a recording potentiometer, which for a number of years has stood the test in many industrial concerns of this country.

The advantages of this recorder are, firstly, the employment of the compensation method for measuring potential and, secondly, its ruggedness, compactness, and multiple-point recording feature. The first seems of special importance in that changes in the circuit

resistance will not affect the magnitude measured and that polarization and other spurious effects at the electrodes will likely be much less with this than with continuous current drawing instruments. The last makes it extraordinarily suitable for obtaining measurements of such a distribution of potentials as is here desired. With the instrument installed at Watheroo the potential differences between a common point and twelve other points can be measured if desired. At first thought the intermittent character of the records seemed an objection, since in the study of shorter period oscillations a continuous record would be more adequate. In that case, however, a more open time-scale would be needed than is practicable for general recording, and an instrument of negligible period, e. g., an Einthoven galvanometer would be required. The unsuitability of the latter type of equipment for general use seems evident.

The possible requirements in earth-current measurements, however, necessitated some important *changes in the measuring circuit* of the standard recorder. These after being designed in outline, were submitted to the Leeds and Northrup Company, where they were developed in detail. In this development it was fortunately found unnecessary to alter more than a few of the mechanical features. The measuring circuit is shown in the diagram (Fig. 7), which is a modification of a sketch supplied by the Leeds and Northrup Company. There is no need here to point out any but the unusual features. In this connection it should first be noted that the potentiometer circuit between A and L is split, one part containing a rotary slide-wire, of 160 ohms resistance, placed in series between two resistances of 160 and 120 ohms, respectively, and the other branch containing eleven, 40 ohm resistance units connected in series. Leads are provided so that connection can be made to the points between these units as well as to the points A and L. This is the chief novel feature of the instrument, and is designed so that not only may positive and negative differences be recorded from different lines at the same time but also that values of a wider difference in magnitude may be accommodated on a higher sensitivity than would be possible without this device. In other words, this arrangement makes it possible to have different base lines for each of the elements that are being recorded. It will be seen that with resistances as indicated in the sketch the point E on the lower branch should have the same potential as E' on the upper branch, and the same should hold for I and I'. Furthermore, if of a pair of electrodes one is



MULTPLE-POINT, MULTIPLE-RANGE, RECORDING POTENTIOMETER

FIG. 7.

connected to the binding post marked "Com." and the other, through the proper binding posts, to the post marked "*E*", and consequently to the points *S* and *E* respectively, on the branches of the "split circuit," then potential differences ranging from 0 to 80 millivolts can be recorded for this pair, when employing the highest sensitivity. If, however, one of the earthed points is in analogous manner connected with *I* instead of *E*, then the range will be from 0 to ***minus*** 80 millivolts. Also, when one line is connected to any point lying between *E* and *I*, the range will be part negative and part positive, and in a similar manner points before *E* will give entirely positive ranges with their zeros shifted beyond the record to the left, while those following *I* will give entirely negative ranges with their zeros shifted to points beyond the record to the right. The two extremes, *A* and *L*, make possible the recording of

values ranging from +80 to +160 and from −140 to −60 millivolts, respectively.

The wide variation in the magnitude of the potentials that this instrument may be called upon to record make it also desirable to have some handy means of changing its sensitivity. This is done by inserting contact plugs in the blocks shown at the lower left-hand corner of the diagram in Fig. 7, and marked "1," ".1," and ".01." With the plugs in the ".01" blocks the highest sensitivity is obtained in which case the recording sheet, which is 25 cm. wide, accommodates a change of potential of 80 millivolts, while for each of the other sensitivities the range is 800 and 8,000 millivolts, respectively.

The *mechanical features of this apparatus* consist briefly of a constant speed motor (shown at the upper right-hand corner of Fig. 8) adjoining it on the left is a group consisting of a suspended-coil type galvanometer and the special "balancing mechanism" which through a clutch and disc, shown in the lower part of the group, turns the potentiometer slide-wire until the unknown E. M. F. is compensated. To the left of this group is a rotary selector switch which places the various circuits in electrical connection with the potentiometer system. As will be seen this switch is designed to accommodate twelve different lines, although the requirement in the present installation is for only six. Nevertheless, this is an advantage in the present case because it admits of recording from the different electrodes in such a sequence as to eliminate any polarization effects that may yet exist in spite of the fact that a potentiometric method is being employed. When the long finger of the switch points upward the circuits are so arranged that the current flowing in the potentiometer circuit is automatically adjusted by balancing against the standard cell.

At the extreme left is a binding post panel, showing at the bottom the six pairs of contact blocks, with the contact plugs in place for employing the intermediate sensitivity. At the left of these are two binding posts for the potentiometer circuit battery. The first of the three columns of binding posts above this, is for the incoming lines. That marked "+COM" is connected with the earthed electrode at *O* of Fig. 1. These binding posts are further connected with the series of studs forming the outer broken annulus on the selector switch. Those of the second column are permanently connected with the inner broken annulus of studs. The switch in effect simply places the galvanometer in series with two like numbered posts. The posts in the third column are the counter-

parts of the correspondingly lettered points of Fig. 7, which have already been discussed. Thus, if it is desired to connect the line coming to binding post No. 4 so that values ranging between equal positive and negative magnitudes may be recorded, the No. 4 binding post of the second column should be connected with post "*G*" of the third column. The lower part of the figure shows the record paper but unfortunately the record was not reproduced in this case. The record is formed by a print wheel attached to the horizontal bar just above the record paper. This wheel is coupled with the potentiometer slide-wire by means of a cat-gut belt so that its motion corresponds with that of the slide-wire. A record point consists of a small asterisk and adjacent to it is a number corresponding to that of the line which is at that time in circuit.

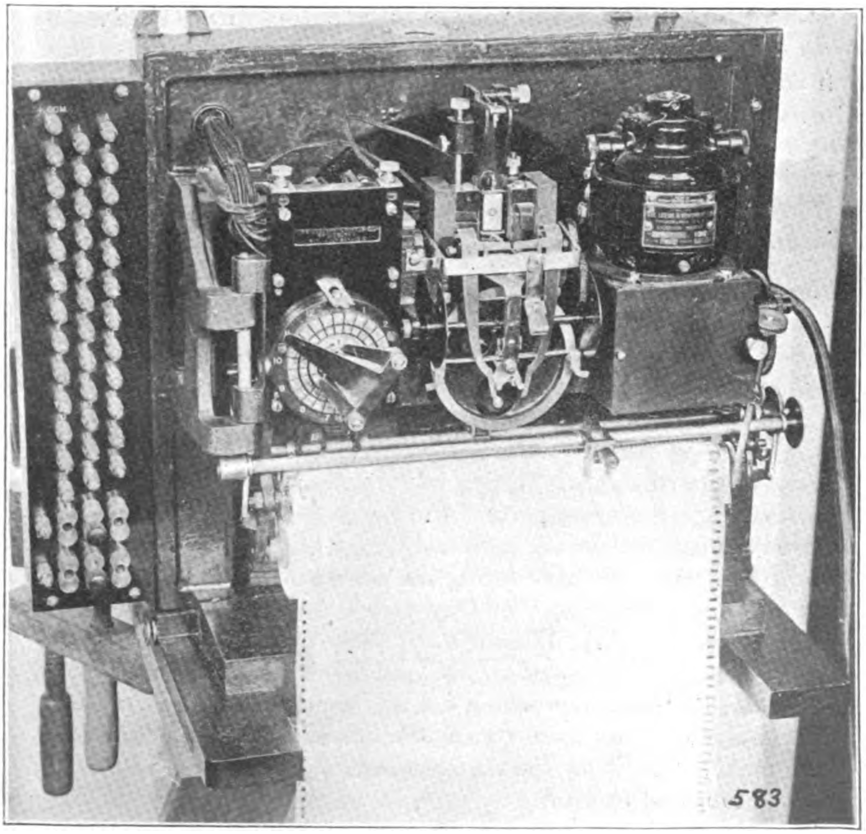


FIG. 8.—Recording Potentiometer, with Cover Removed.

Instrumental control. Because of the continual motion of the potentiometer slide-wire it is subject to more wear than in a manually operated instrument so that the *calibration of the recorder* should be checked from time to time. A portable hand operated potentiometer with suitable range is provided for this purpose. Preliminary tests so far show no measurable change in this respect, however, occasional cleaning of the slide-wire shows improvement in the accuracy with which a definite value can be registered. Numerous trials show that this recorder will, on high sensitivity, automatically register a given value to within $\pm$ 0.2 milli-volt, which is closer than the constancy which may be reasonably expected of the electrodes.

The *rate of the constant speed motor* is surprisingly steady. Preliminary tests extending over several weeks show no rate in any 24-hour period, which differed from the average by more than ± 0.03 per cent. This was under conditions where the temperature varied from 19° to 32° C. It should, however, be mentioned that in these tests the E. M. F. actuating the motor was derived from a 300 ampere-hour capacity storage battery. With such constancy of rate it will be possible, from the time control observations made twice daily, to compute the time of any recorded point with a maximum error of $\pm$ 7 seconds.

It has been the aim here to set forth only the more important features of the lines and equipment for measuring earth-current potentials at Watheroo. It is planned to give more details and preliminary results in a later paper.

This earth-current recording system is the first realization of a long standing desire on the part of Dr. Louis A. Bauer, Director of the Department of Terrestrial Magnetism, to include earth-current registration as part of the program at the Department's observatories. To Dr. S. J. Mauchly, for his valuable suggestions and stimulating criticism during the course of many informal conferences and to the Assistant Director, John A. Fleming, especially for his generosity in shouldering many of the responsibilities incident to the "long distance engineering," peculiar to this undertaking and to Dr. G. R. Wait upon whom fell the brunt of installing the lines and equipment—to these colleagues grateful acknowledgment is here made. Credit for the sketches in this paper is due to Messrs. C. C. Ennis and C. Huff.

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON.

LETTERS TO EDITOR

PROVISIONAL SUN-SPOT NUMBERS FOR APRIL TO JUNE, 1923.

Day	April	May	June	Day	April	May	June	Day	April	May	June
1	12	0	16	11	0	0	0	21	14	0	9
2	10	0	10	12	0	8	0	22	14	7	8
3	0	0	10	13	8	9	0	23	13	8	7
4	0	0	..	14	..	6	0	24	10	11	7
5	0	0	0	15	0	0	0	25	7	11	38
6	0	0	0	16	0	0	0	26	8	..	..
7	0	0	0	17	..	0	0	27	..	0	23
8	..	0	0	18	13	0	13	28	..	..	20
9	0	0	0	19	7	0	13	29	7	7	31
10	0	..	0	20	11	7	8	30	..	7	37
								31		8	
Mean for month.....								.....	5.4	3.2	9.0

Zurich, June 30, 1923. A. WOLFER.

LERWICK OBSERVATORY, SHETLAND ISLANDS.

Officer in Charge: J. Crichton, M.A., B.Sc.

Position: Latitude, 60°8′45″N; Longitude, 1°10′50″W; Height above M. S. L., 79.3 metres.

The object of the Observatory is the study of terrestrial magnetism and auroral phenomena. The magnetic elements (declination, horizontal force, vertical force) are recorded photographically in a brick-walled concrete building. Absolute observations are made twice weekly.

A watch is kept on all visible aurorae, and the changes in form are noted from minute to minute. Preparations are being made for eye readings of declination and horizontal force during the occurrence of aurorae, and also for the measurement of minute changes in vertical force.

The Observatory began the regular routine work as above on 1st January, 1923. A. CRICHTON MITCHELL.

NOTES

14. *Munich Geophysical Observatory.*—According to information received from Prof. Dr. C. W. Lutz, the three observatories connected with the Munich Astronomical Observatory devoted, respectively, to terrestrial magnetism (Erdmagnetisches Observatorium), seismology (Erdbebenwarte), and atmospheric electricity (Luftelektrische Beobachtungsstelle), will henceforth be known under the combined official designation, "Erdphysikalische Warte b. d. Sternwarte München."

15. *Potsdam Meteorological and Magnetic Observatory.*—For the purpose of combining the work of the Aeronautical Observatory in Lindenberg and the Meteorological Institute in Berlin with its dependent Observatory in Potsdam, a Board of Directors has been formed, to which belong the director (Prof. Dr. H. Hergesell) of the Aeronautical Observatory and the director (Prof. Dr. H. v. Ficker) of the Meteorological Institute. The functions of the Board of Directors, of which the chairman is Prof. Hergesell, consist in consulting on affairs common to the institutes, or of general scientific import, and of reporting thereon as necessary, to the Ministry. In the administration of the two institutes, the change consists in the fact that the scientific direction of the Meteorological Observatory in Potsdam is entrusted to the director of the Aeronautical Observatory, with the exception of the Magnetic Observatory in Potsdam which remains in the charge of Prof. Dr. Adolf Schmidt.

16. *Greenwich Magnetic Observatory.*—On account of disturbing influences from electric railroads and tramways, it has been decided to move this magnetic observatory, at which observations were begun in 1840, to Holmbury St. Mary in Surrey. The South Eastern and Chatham Railway Company has decided to electrify its local services, which run in the near vicinity of the present site of the Observatory, and the Company has agreed to defray the costs of the removal of the magnetic observatory and the extra cost of maintenance thereby involved. (From *Nature*, Sept. 1, 1923, p. 345.)

17. *Personalia.*—We note with regret the death of Father *E. Colin*, S. J., at the age of 71 years, a zealous missionary and founder and director of the Observatory of Tananarive, Madagascar. Prof. *K. Schering* retired in October, 1922, from the directorship of the Physikalisches Institut der Technischen Hohschule, Darmstadt; he has been succeeded by Prof. *H. Rau*.

The following appointments are noted: Dr. *Jean Bosler* as director of the Observatory of Marseilles to succeed M. *Bourget*, deceased; Dr. *D. la Cour*, as director of Det Danske Meteorologiske Institut to succeed Captain *C. H. Ryder*, deceased; Dr. *T. Royds*, as director of the Kodaikanal and Madras Observatories in succession to Mr. *J. Evershed*, who retired on February 25, 1923.

LIST OF RECENT PUBLICATIONS

A. Terrestrial and Cosmical Magnetism.

AUGIÉRAS (Capitaine). Mission transsaharienne Alger-Dakar (1920-1921). Géographie, Paris, T. 39, No. 1, Jan., 1923 (1-35 avec 1 carte). [Declination values are given for 11 stations.]

BANGKOK. Report on the operations of the Royal Survey Department of the Army for the year 1920-1921. Bangkok, Bangkok Daily Mail, 1922 (43 with maps and pls.). 34 cm. [Contains results of magnetic observations 1905-1921.]

BATAVIA. Koninklijk Magnetisch en Meteorologisch Observatorium te Batavia. Jaarverslag 1922. Weltevreden, Landsdrukkerij, 1923 (26). 22 cm. [On pp. 11-12 is a brief notice of the magnetic work during 1921.]

BAUER, L. A. Some physical aspects of a recent analysis of the earth's magnetic field. Science, New York, N. Y., N. S., v. 58, No. 1494, Aug. 17, 1923 (113-115).

BAUER, L. A. The earth's magnetic field for 1922. Nature, London, v. 112, No. 2808, Aug. 25, 1923 (295-298).

BAUER, L. A., AND J. A. FLEMING. Magnetic observations during the total solar eclipse [September 10, 1923]. Science, New York, N. Y., N. S., v. 58, No. 1491, July 27, 1923 (62-63).

BOCHUM. Auszug aus den Ergebnissen der Deklinations-beobachtungen zu Bochum und Langenberg im Jahre 1922. (Mitteilung der erdmagnetischen Warten der Westfälischen Berggewerkschaftskasse zu Bochum.) S.-A. Glückauf, 1923, Nr. 12, 2 pp. [Accompanied by 12 plates showing declination curves for each day of the year 1922.]

BRAZIER, C. E. L'agitation magnétique au Parc Saint-Maur et au Val-Joyeux et ses relations avec l'activité solaire. Paris, C.-R. Acad. sci., T. 176, No. 25, 18 juin 1923 (1821-1824).

BRUXELLES, INSTITUT ROYAL MÉTÉROLOGIQUE DE BELGIQUE. Annuaire météorlogique pour 1916, publié par les soins de J. Vincent, Directeur. Bruxelles, Hayez, 1919 (vi+200). 18-½cm. [Contains "Le magnétisme terrestre" pp. 104-117, and "Résumé annuel du magnétisme terrestre à Uccle" pp. 118-120.]

BRUXELLES, INSTITUT ROYAL MÉTÉOROLOGIQUE DE BELGIQUE. Annuaire météorologique pour 1917, publié par les soins de J. Jaumotte, Directeur. Bruxelles, Hayez, 1920 (vi+106). 18-½cm. [Contains "Résumé annuel du magnétisme terrestre à Uccle," années 1915 et 1916, pp. 32-36.]

BUBNOFF, S. VON. Ueber die magnetischen Anomalien im Gouvernement Kursk. Zs. angew. Geophysik, Berlin, Bd. 1, Heft 5, Juni 1923 (144-149).

CANADA, TOPOGRAPHICAL SURVEY. Lines of equal magnetic declination and of equal annual change in Canada for 1922. Ottawa, Dept. Int. Canada, Topogr. Surv., 1923 43x82 cm.

CANADA, TOPOGRAPHICAL SURVEYS BRANCH. Isomagnetic maps of Western Canada for 1922.0. (Lines of equal magnetic declination and of equal annual change in Western Canada for 1922.0; Lines of equal magnetic inclination in Western Canada for 1922.0 and of equal annual change between 1917.0 and 1922.0; Lines of equal magnetic horizontal intensity in Western Canada for 1922.0 and of equal annual change between 1917.0 and 1922.0.) Ottawa, Dept. Int. Canada, Topogr. Surv. Branch, [1923] 54x74 cm.

COPENHAGEN, DET DANSKE METEOROLOGISKE INSTITUT. Magnetisk aarbog. Annuaire magnétique. 1921. Kjøbenhavn, G. E. C. Gad, 1923 (11 avec 7 pls.). 32 cm.

DE BILT, METEOROLOGICAL AND MAGNETICAL OBSERVATORY. Annuaire. Soixante-treizième année 1921. B. Magnétisme terrestre. (K. Nederlandsch Meteor. Inst. No. 98.) Utrecht, Kemink & Zoon, 1922 (xi+24). 23½ cm.

HAALCK, H., UND G. BRINCKMEIER. Erdmagnetische Untersuchungen am Salzstock der Burbacher Achsenzone bei Wefensleben. Zs. angew. Geophysik, Berlin, Bd. 1, Heft 4, Mai 1923 (116-122).

HONGKONG, ROYAL OBSERVATORY. Monthly meteorological bulletin, December, 1922. Containing detailed results of observations made at the Royal Observatory, Hongkong, and the daily weather reports from various stations in the Far East. Prepared under the direction of T. F. Claxton, Director. Hongkong, Noronha and Co., 1922 (ca. 64 pp. with 2 pls.). 32 cm. [Contains "Results of Magnetic Observations, 1922."]

HONGKONG, ROYAL OBSERVATORY. Report of the Director of the Royal Observatory, Hongkong, for the year 1922. (T. F. Claxton, Director.) Hongkong, Noronha and Co., 1923 (17). 24 cm.

INDIA, SURVEY OF. Records of the Survey of India, Volume XVI (Supplementary to general report 1920-21). Annual reports of parties and offices 1920-21. Prepared under the direction of Colonel C. H. D. Ryder, C. B., C. I. E., D. S. O., R. E., Surveyor General of India. Dehra Dun, Office Trigonometrical Surv., 1922 (140 with charts and illus.). 34 cm. [Pp. 77-86 contain account of the Magnetic Survey and mean values of the magnetic elements at the various observatories for 1920.]

INDIA, SURVEY OF. General report, 1921-1922. From 1st October 1921 to 30th September 1922. Prepared under the direction of Colonel C. H. D. Ryder, C. B., C. I. E., D. S. O., R. E., Surveyor General of India. Calcutta, 1923 (49 with 8 maps). 34 cm. [On pp. 24-25 is a brief report of the Magnetic Survey and the mean values of the magnetic elements at the various observatories for 1921.]

LAZAREV, P. L'anomalie magnétique dans le gouvernement de Koursk. Pétrograd, Annexe Procès-Verbaux Acad. sci., 1921, 12pp. 27 cm.

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VOLUME XXVIII NUMBER 4

TERRESTRIAL MAGNETISM

AND

ATMOSPHERIC ELECTRICITY

An International Quarterly Journal

December, 1923

Conducted by

LOUIS A. BAUER

With the Co-operation of Eminent Investigators.

CONTENTS

PUBLISHED FOR

THE JOHNS HOPKINS PRESS, BALTIMORE

THE ABINGDON PRESS, 420 PLUM ST., CINCINNATI, O.

THREE DOLLARS AND FIFTY CENTS A YEAR SINGLE NUMBERS, ONE DOLLAR

WHELDON & WESLEY, Ltd.,
2, 3 and 4 Arthur Street,
New Oxford Street,
LONDON, W. C., 2

THE ABINGDON PRESS
(Cash Subscriptions)
420 Plum St., CINCINNATI

Entered as second-class matter at the Post-office at Cincinnati

Terrestrial Magnetism *and* *Atmospheric Electricity*

VOLUME XXVIII DECEMBER, 1923 No. 4

THE NORMAL DISTRIBUTION OF TERRESTRIAL MAGNETISM OVER SIBERIA IN 1910.

BY BORIS WEINBERG.

1. This article is based on my three unpublished investigations on the distribution of the inclination,[21] of the declination,[26] and of the horizontal intensity[27] over Siberia, and is published in somewhat different form in Russian.[30] The publication of the Russian abstract, instead of the three quoted articles *in extenso*, was necessitated on the one hand by my proposal of a magnetic survey of Siberia,[29] and by the desirability of having data on the distribution of terrestrial magnetism over Siberia in connection with the actual conclusion of the general magnetic survey of the globe by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington on the other hand. If Asiatic Russia, which covers over a ninth part of the land area of the globe, occupies the last place in the list of the large continental countries as concerns magnetic surveys, this defect can partly be compensated for by summaries of all determinations of the magnetic elements thus far made and by theoretical investigations based on the results obtained. The paucity of distribution of magnetic stations over even such easily accessible parts of Siberia as the provinces of Akmolinsk and Semipalatonsk was shown by me in a special paper with its accompanying chart.[8] For the whole area of Siberia the portion which is entirely unexplored magnetically is equal to 86 per cent,[15] but even the distribution of the magnetic stations for the remaining 14 per cent is very irregular.

2. As the material for finding the distribution of the declination, D, of the inclination, I, and of the horizontal intensity, H, I have used all published (or prepared-for-print) determinations made from 1820 to 1918 and reduced to 1910[22] by means of the values of the secular variation found by me (Refs. 18 and 19). Besides the 819 determinations of D made by means of special magnetometers, and 202 published determinations made by means of needle declinometers, I have used also 3,279 unpublished determinations of declination made by different state departments,[25] which have been extracted by me from the archives of these departments. The results of these determinations were represented mostly by statements of the "deflection of the magnetic needle from the true meridian," given on different plans and maps.

The possibility of using such determinations, which in general have but a very moderate degree of precision and are sometimes not entirely trustworthy, was proved by a preliminary study of such determinations for the government of Yenisei (Ref. 14, also 15, p. 32.) For this part of Siberia, the mean "deflection" of such departmental determinations from a set of rectilinear and equidistant isogonics obtained by the method of least squares was $\pm 36'$, and for the special magnetometer-determinations (Refs. 1, 2, 9, 13, and 17), the "deflection" was $\pm 26'$. Hence, if we assume the error due to the diurnal-variation correction to be equal to $\pm 5'$, and the error of the magnetometer-determination equal to $\pm 2'$, the probable magnitude of local disturbances is $\pm 25'$, and the error of one departmental determination, $\pm 23'$. In favor of using these departmental observations, I can add that the average of the weighted mean values of the deflections of the separate values of declination (reduced to 1910) at a certain point from the mean value of the declination for 1910 at this point is $\pm 14'$ for the magnetometer-determinations and, $\pm 26'$ for the departmental ones (Ref. 25, paragraph 2).

3. The departmental determinations of magnetic declination being numerous and of moderate precision, they were combined into groups. A map of Siberia was divided for this purpose into rectangular sections having sides in the ratio of 4 to 1. The long sides were taken parallel to the meridians or latitude circles or at an angle of 45° with them, according to the direction of the isogonics in the region as given on a preliminary chart.[5] The values of declination, taken from this preliminary chart, for all the points lying inside the section, were reduced to the central point of the section by means of the values of $\Delta D/\Delta\phi$ and $\Delta D/\Delta\lambda$ (the ratios of change in declination to changes of latitude and longitude, ϕ, λ). The uncertainty of such reduction is much less than the possible error of the observations, and the resulting simplification of further reductions is considerable; instead of 3,279 values of declination, there were obtained thus only 566 for *equidistant* points.

The published determinations with the needle declinometers (Ref. 22, Table V) being of nearly the same degree of precision, were treated in the same manner.

4. For tracing the isogonic, isoclinic, and H-isodynamic lines, the positions of "isopoints," or the points with equal values of magnetic element, were found: of declination at two degrees intervals, inclination at one degree intervals, and horizontal intensity at intervals of 0.01 C.G.S. For this purpose, the area which has been the subject of investigation (from $\phi=45°$ to $\phi=65°$ and from $\lambda=60°$E to $\lambda=135°$E) was divided in portions for which the "isolines," or lines of equal magnetic values, could be assumed as straight and equidistant with an error not exceeding the probable order of the local disturbances according to preliminary charts

(for declination, see Ref. 5). For each of these portions, the observed values of the element reduced to 1910, E_{10}, were adjusted by the method of least squares to the formula

$$E_{10} = a + b\,(\lambda - \lambda_0) + c\,(\phi - \phi_0), \qquad (1)$$

where λ_0 and ϕ_0 are the longitude and the latitude of a certain central point, λ and ϕ, the variable longitude and latitude, and a, b and c, the coefficients to be determined.

Since almost all the magnetic determinations in Siberia are the results of expeditions along routes, of which considerable portions can be considered rectilinear without sensible error, it was sufficient in most cases to use two terms instead of three in formula (1). When formula (1) was unsuited to any region, because of irregularities of distribution of data, I simply calculated the weighted means of the geographic coordinates and the weighted mean of the magnetic element. Points of equal values ("isopoints") to trace the magnetic curves near these weighted mean positions were then obtained by linear interpolation between these weighted means and other points, previously plotted, which were situated favorably for the interpolation. This method of finding "isopoints" for tracing the magnetic curves, as compared with the usual method, is treated by me elsewhere (Ref. 28, paragraphs 11-13).

5. In all these computations, weights were taken into account which were assigned to the values of the magnetic elements according to the degree of precision of the determinations and to the reliability of the reduction to 1910. For magnetometer-determinations of declination, inclination, and horizontal intensity, these weights (Ref. 22, columns 8, 11 and 14 of Table IV) were 10 as a general rule for observations of 1900 to 1918, 6 for the decade of the seventies of last century and 3 for the decade of the thirties. These weights were decreased for determinations near the boundaries of the region, also for determinations of inferior precision and for places where magnetic disturbance was suspected. A weight, zero, was assigned to determinations at stations undoubtedly anomalous.

The weight of one departmental determination, as a general rule, owing to the difficulty of their critical examination, was taken equal to 2, because the mean value of the difference, $\triangle$, of a magnetometer-determination of declination with a weight 1 from the weighted mean value $\bar{D}$ for the same point, calculated by means of the formula

$$\triangle_1 = \triangle\sqrt{\frac{\Sigma\, p}{n}} \qquad (2)$$

is equal to $\pm 36'$ and the analogous mean difference of the values D_{10} for the departmental determinations, is, as has been already mentioned, equal to $\pm 26'$, and the ratio of $\pm 36^2$ to $\pm 26^2$ is very nearly 2 to 1; $\triangle$ is the weighted mean difference of the separate values D_{10} from their mean value $\bar{D}$, $\Sigma\, p$, the sum of their weights,

and n, their number. But in assigning the weights to the mean values of D_{10}, derived from departmental determinations, for different stations or for the equidistant points quoted in paragraph 3, I often diminished this weight in comparison with the sum of the weights of the single values according to the probability of the supposition that the statement of the "deflection of the magnetic needle" on the chart was merely a repetition of a similar inscription on a previous chart of the same place, or on a chart of an adjacent locality, according to the degree of concordance of the values of D_{10}, etc.

The same method of assuming the weights was applied to the determinations made with the needle declinometers.

In the cases when formula (1) was used with only two terms, I readily obtained the position of the "isopoints" by equating the left side to the proper value of the element. To the set of values (λ, ϕ) thus found was assigned a weight equal to the sum of the weights of the element at the surrounding stations, with a certain rounding off for simplification of further computations, and with a certain diminution if the differences from formula (1) were considerable.

If formula (1) contains all three terms, it determines only the lines of equal values. On these "isolines" there were chosen one or two (sometimes even three) "isopoints" corresponding to, as it were, the "centers of gravity" of the determinations at the surrounding points. As the weight of the corresponding set of the values of ϕ and λ, there was taken also the sum of the weights at the surrounding points, again with certain rounding off and reductions.

The positions of all the "isopoints" obtained in the manner described were represented on manuscript charts, I to III, by circles, and the departmental determinations of declination were indicated by squares; the areas of the circles and squares were taken proportional to the weight of the "isopoint."

6. Every value of E_{10} at a certain point used for finding the "isopoints" differs from the real mean value of E for 1910 at the same point, this difference being caused by:

(*a*) errors of observation and of the constants of the instruments;

(*b*) possible presence of accidental and periodic changes of the element during the observations;

(*c*) errors in reduction to the mean annual value for the year when the observations were made;

(*d*) errors in reduction to 1910;

(*e*) The probable presence of a purely local disturbance; and

(*f*) the presence of disturbances, the influence of each of which is spread over a more or less considerable region—the "regional" disturbances according to the terminology proposed by me (Ref. 28, paragraph 10).

Therefore, even the question of finding the "real" distribution of magnetic elements over Siberia in 1910 is excluded, and we can

deal only with the problem of finding the "smoothed" distribution in which the influence of the *local* disturbances should be practically eliminated, or of the "normal" distribution, in which the *regional* disturbances should be considerably diminished and there should remain only such disturbances the influence of which is felt over nearly the whole investigated part of the Earth's surface.

If the value of the element at a certain point for 1910 results from several determinations made at different epochs, the errors (*a*), (*b*), (*c*), and (*d*) will be decreased more or less. Similarly, if the position of an "isopoint" results from determinations at several points, the errors (*e*) and partly (*f*) will be eliminated to some extent. Following this idea we can attempt to decrease still more the influence of local and regional disturbances by drawing the magnetic curves as near to the plotted points as smoothness permits rather than actually through them. In order to accomplish this mathematically, I made use of the fact that the plotted "isopoints", for the most part, fall in rather narrow, parabola-like strips.

Accordingly, for each magnetic curve I have computed by the method of least squares the coefficients ϕ_o, b' and c', of a formula

$$\phi = \phi_o + b' (\lambda - \lambda_o) + c' (\lambda - \lambda_o)^2, \qquad (3)$$

in which λ_o is the longitude of an assumed central point. For the eastern part of the region studied on the isogonic chart a similar equation was used containing, however, the first and second powers of $(\phi - \phi_o)$ instead of the powers of $(\lambda - \lambda_o)$.

Formula (3), as well as the positions of the "isopoints" which served to compute the curves, are given *in extenso* in the quoted articles (Refs. 21, 26 and 27). The parabolic curves given by these formulas were represented as full lines on the manuscript charts I to III.

7. Since the parabolas given by formula (3) can not be expected to represent perfectly the actual magnetic field sought, I returned to smoothing the differences between the computed and original values in order to obtain magnetic curves passing still nearer to original values and therefore somewhat more free from regional disturbances for regions of rather small extent.

For simplification in applying the methods of smoothing, each of these differences was assumed to belong to the nearest of the equidistant meridians (parallels for the eastern parts of the isogonic chart). In the cases when to an intersection of a certain parabola with a meridian (vice versa with a parallel), several "isopoints" corresponded with their differences, there were taken the weighted mean values of these differences.

For this smoothing, I have used the expression

$$\begin{aligned}\Delta'_p = 0.02\Delta_{p-2} + 0.23\Delta_{p-1} \\ + 0.50\Delta_p + 0.23\Delta_{p+1} + 0.02\Delta_{p+2},\end{aligned} \qquad (4)$$

where Δ'_p is the smoothed difference at the point p, Δ_p the ob-

served difference at the same point, Δ_{p-1} and Δ_{p+1} the observed differences at the equidistant adjacent points, both sides of the point p, Δ_{p-2} and Δ_{p+2}, at the two next ones.

Formula (4) corresponds to two assumptions:

(*a*) the probability that the influence of the local and the regional disturbances is equal to Δ_p varies according to Gauss's law with the distance from the point p;

(*b*) the sum of the probabilities, that the difference Δ_p expresses the influence of the local and the regional disturbances along the segment of the "isoline" from the point bisecting the distance between the point p and the point $(p-1)$ to the point bisecting the distance between the point p and the point $(p+1)$, is equal to the sum of the probabilities, that these disturbances are equal to Δ_p for both parts of the "isoline" outside of the two quoted points.

This method is treated in detail in other articles (Refs. 20, paragraphs 13-15, and 28, paragraph 6), where it is compared theoretically and practically with other methods proposed for the smoothing.

8. If the general distribution of the "isopoints" indicates considerable regularity of the position of the points corresponding to a given value of the element, we may expect to meet similar regularity in the variations of the distances between the consecutive curves. Indeed, an inspection of the manuscript charts giving the parabolic "isolines," or of the tables giving the coordinates of the smoothed "isolines," shows clearly that these distances are either practically constant, or vary rather regularly. Therefore, the third step towards finding the "normal" distribution of the element was to express the smoothed values of the latitude, or of the longitude, just mentioned by a formula

$$\phi = \phi_0 + b'' (E - E_0) + c'' (E - E_0)^2, \qquad (5)$$

where ϕ_0, b'' and c'' are the coefficients to be determined by least-squares, and E_0 is a certain average value of the element at the latitude ϕ_0 (or by a similar formula for λ and λ_0).

The fourth and last step in the direction of finding the normal distribution consisted in computing the differences Δ between the values of the latitude (or longitude) of the intersections of the smoothed "isolines" with the equidistant meridians (or parallels) from which the calculation of the coefficients ϕ_0, b'' and c'' of the formulas of type (5) and the values of ϕ (or λ) given by these formulas, had departed, and in the smoothing of these differences by means of the expression (4). The articles quoted several times (Refs. 21, 26 and 27) give for each element:

(*a*) the latitudes (or longitudes) of the intersections of the parabolic "isolines" (3) with the meridians (or parallels);

(*b*) the latitudes (or longitudes) obtained by means of the smoothing of the differences of the latitudes (or longitudes) of the

"isopoints" from the latitudes (or longitudes) given by the formulas of type (3);

(*c*) the latitudes (or longitudes) of the intersections of the curves with the meridians (parallels) given by the formulas of type (5); and

(*d*) the latitudes (or longitudes) obtained by means of the smoothing of the differences between the values (*b*) and (*c*).

The latter values were taken as final and as representing the normal distribution, and through the points corresponding to these values of ϕ and λ were traced on manuscript charts I to III, by hand, the smoothly running isolines finally adopted.

9. In order to find the values of the three rectangular components (X, positive towards geographic North; Y, positive towards geographic West; and Z, positive towards Nadir), I computed from the values (*d*) of ϕ and λ just mentioned, the values of D, I and H corresponding to the intersections of equidistant meridians with equidistant parallels. These values of D, I and H, as well as the resulting values of X, Y and Z are given in Table 1; all longitudes are East of Greenwich.

Owing to the practical importance of the declination, I have computed, by means of an approximate assumption (Ref. 22, p. 4) as to the change of D, based on the data of Ekaterinburg and Irkutsk observatories for 1910 to 1918, the probable values of D for 1920 and have published the resulting table.[23]

Manuscript charts IV to VI, showing the curves for X, Y and Z, were constructed from the values of these quantities given in Table 1.

10. A thorough examination of the results of the determinations of magnetic elements made by other authors as well as of the 11 expeditions made for this purpose by me and by my coworkers (Refs. 4, 6, 7, 9 to 13, 16, 17, 24, 31 to 33) covering about 60,000 kilometers and giving determinations at 391 points, has shown a great smoothness in the distribution of terrestrial magnetism over the greater part of the explored area of Siberia, a circumstance which has permitted and stimulated the present investigation. As disturbed or anomalous regions can be considered:

(*a*) the mountains of Altai;

(*b*) the Lake of Baikal and its surroundings;

(*e*) the basin of the River Aldan;

(*d*) the lower part of the Yenisei, where it finally cuts through the mountains before reaching the ocean; and

(*e*) the coal and iron basin of Kuznetck.

But of these regions only Baikal can be considered as more or less explored by the work of Driyenko and Voznesenskij,[3] at least as concerns the declination. Partly investigated is Altai (Refs. 4, 7, 10 and 11) and the "cheeks" of Yenisei (Refs. 6 and 9), and almost unexplored are the Aldan and the basin of Kuznetck.

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TABLE 1.—*Values of the magnetic elements and magnetic components over Siberia in 1910.*

(West declination is taken as positive; the quantities in parentheses are extrapolated values.)

Long. (E. of Gr.)	*D*	*I*	*H*	*X*	*Y*	*Z*	*D*	*I*	*H*	*X*	*Y*	*Z*
	Parallel 65° North						Parallel 63° North					
°	° ′	° ′	c.g.s.	c.g.s.	c.g.s.	c.g.s.	° ′	° ′	c.g.s.	c.g.s.	c.g.s.	c.g.s.
60	−17 55	75 02	.1410	.1342	−.0434	.5274	−16 21	73 58	.1516	.1455	−.0427	.5275
65	(−19 10)	75 48	.1343	(.1268)	(−.0441)	.5308	−17 47	74 44	.1468	.1398	−.0448	.5378
70	(−20 35)	76 31	......	......	......	......	(−18 50)	75 23	.1413	(.1337)	(−.0456)	.5418
75	(−20 45)	(77 18)	......	......	......	......	(−19 15)	76 04	(.1365)	(.1289)	(−.0450)	(.5502)
80	(−20 00)	77 42	......	......	......	......	−18 46	76 50	......	......	......	......
85	(−18 50)	78 15	......	......	......	......	−17 20	77 19	......	......	......	......
90	−17 04	78 54	......	......	......	......	−15 12	77 49	......	......	......	......
95	−14 03	......	......	......	......	......	−12 49	78 02	......	......	......	......
100	−11 28	......	......	......	......	......	−10 12	78 17	......	......	......	......
105	−8 30	......	......	......	......	......	−6 25	78 22	......	......	......	......
110	−2 47	......	......	......	......	......	−1 33	78 19	......	......	......	......
115	(+2 05)	......	......	......	......	......	+2 32	(78 15)	......	......	......	......
120	+5 48	......	......	......	......	......	+6 05	77 52	......	......	......	......
125	(+9 55)	......	......	......	......	......	(+9 00)	77 14	(.1360)	(.1343)	(+.0213)	(.6002)
130	......	(78 20)	......	......	......	......	......	76 28	.1411	......	......	.5862
135	......	77 11	......	......	......	......	......	75 46	.1465	......	......	.5776
Long.	Parallel 61° North						Parallel 59° North					
°	° ′	° ′	c.g.s.	c.g.s.	c.g.s.	c.g.s.	° ′	° ′	c.g.s.	c.g.s.	c.g.s.	c.g.s.
60	−15 04	72 59	.1606	.1551	−.0417	.5248	−13 49	71 53	.1681	.1632	−.0399	.5138
65	−16 27	73 35	.1570	.1506	−.0445	.5329	−15 05	72 29	.1666	.1609	−.0434	.5275
70	−17 17	74 13	.1528	.1459	−.0454	.5406	−15 42	73 04	.1634	.1573	−.0442	.5373
75	−17 36	74 51	.1488	.1418	−.0450	.5496	−15 45	73 38	.1606	.1546	−.0436	.5471
80	−16 46	75 28	.1450	.1387	−.0418	.5590	−15 08	74 09	.1579	.1524	−.0412	.5562
85	−15 32	76 10	.1410	.1358	−.0378	.5726	−14 04	74 44	.1543	.1497	−.0376	.5653
90	−13 39	76 41	(.1385)	(.1346)	(−.0327)	(.5851)	−12 21	75 16	.1520	.1485	−.0325	.5780
95	−11 17	77 00	(.1375)	(.1348)	(−.0269)	(.5954)	−10 01	75 35	.1493	.1470	−.0259	.5808
100	−8 59	77 11	(.1350)	(.1333)	(−.0211)	(.5934)	−7 47	75 50	.1473	.1459	−.0199	.5836
105	(−4 30)	77 12	(.1325)	(.1321)	(−.0104)	(.5832)	−3 15	75 57	.1489	.1487	−.0084	.5950
110	+0 28	77 09	(.1350)	(.1350)	(+.0011)	(.5918)	+1 03	75 50	.1508	.1508	+.0028	.5974
115	+4 01	76 52	(.1385)	(.1382)	(+.0097)	(.5936)	+4 13	75 29	.1534	.1530	+.0113	.5924
120	+6 21	76 23	.1437	.1428	+.01[illegible]9	.5932	+6 16	74 54	.1570	.1561	+.0171	.5819
125	+8 20	75 42	.1482	.1466	+.0215	.5814	+8 05	74 09	.1617	.1601	+.0227	.5695
130	(+10 00)	75 05	.1539	(.1516)	(+.0267)	.5777	(+9 50)	73 15	.1695	(.1670)	(+.0289)	.5632
135	......	74 34	.1610	......	......	.583[illegible]	......	72 27	.1756	......	......	.5552
Long.	Parallel 57° North						Parallel 55° North					
°	° ′	° ′	c.g.s.	c.g.s.	c.g.s.	c.g.s.	° ′	° ′	c.g.s.	c.g.s.	c.g.s.	c.g.s.
60	−12 34	70 38	.1765	.1723	−.0384	.5021	−11 21	69 22	.1870	.1833	−.0368	.4966
65	−13 40	71 11	.1763	.1713	−.0417	.5174	−12 21	69 48	.1873	.1830	−.0401	.5091
70	−14 08	71 47	.1748	.1695	−.0427	.5311	−12 48	70 17	.1868	.1822	−.0414	.5212
75	−14 06	72 19	.1729	.1677	−.0421	.5423	−12 47	70 50	.1855	.1809	−.0410	.5337
80	−13 43	72 49	.1705	.1656	−.0404	.5514	−12 28	71 21	.1834	.1791	−.0396	.5434
85	−12 46	73 17	.1682	.1640	−.0372	.5600	−11 31	71 51	.1817	.1780	−.0363	.5543
90	−11 03	73 45	.1662	.1631	−.0319	.5702	−9 47	72 11	.1802	.1776	−.0306	.5607
95	−8 52	74 08	.1635	.1615	−.0252	.5752	−7 49	72 31	.1788	.1771	−.0243	.5677
100	−6 20	74 22	.1621	.1611	−.0179	.5793	−5 22	72 45	.1778	.1770	−.0166	.5726
105	−2 11	74 25	.1634	.1633	−.0062	.5859	−1 42	72 52	.1769	.1768	−.0052	.5738
110	+1 38	74 18	.1652	.1651	+.0047	.5877	+1 34	72 50	.1769	.1768	+.0048	.5726
115	+4 24	73 56	.1679	.1674	+.0129	.5830	+4 11	72 24	.1829	.1824	+.0133	.5766
120	+6 19	73 02	.1720	.1710	+.0189	.5638	+6 19	71 51	.1870	.1859	+.0206	.5704
125	+8 11	72 17	.1784	.1766	+.0254	.5584	+8 10	71 12	.1880	.1861	+.0267	.5522
130	(+9 50)	71 41	.1824	(.1797)	(+.0312)	.5510	(+9 50)	70 44	.1905	(.1871)	(+.0325)	.5450
135	......	71 22	.1857	......	......	.5507	......	70 10	.1939	......	......	.5376

TABLE 1.—*Values of the magnetic elements and magnetic components over Siberia in 1910.—Concluded.*

(West declination is taken as positive; the quantities in parentheses are extrapolated values.)

Long. (E. of Gr.)	D	I	H	X	Y	Z	D	I	H	X	Y	Z
	Parallel 53° North						Parallel 51° North					
°	° ′	° ′	c.g.s.	c.g.s.	c.g.s.	c.g.s.	° ′	° ′	c.g.s.	c.g.s.	c.g.s.	c.g.s.
60	−10 19	68 01	.1994	.1962	−.0357	.4939	−9 32	66 16	.2106	.2077	−.0349	.4790
65	−11 10	68 24	.1991	.1953	−.0386	.5029	−10 08	66 42	.2105	.2072	−.0370	.4888
70	−11 36	68 54	.1983	.1942	−.0399	.5139	−10 33	67 11	.2099	.2064	−.0384	.4989
75	−11 39	69 20	.1975	.1934	−.0399	.5236	−10 39	67 47	.2093	.2057	−.0387	.5124
80	−11 20	69 49	.1971	.1932	−.0387	.5362	−10 14	68 10	.2089	.2056	−.0371	.5214
85	−10 19	70 13	.1952	.1920	−.0350	.5427	−9 07	68 33	.2087	.2061	−.0331	.5312
90	−8 34	70 35	.1945	.1923	−.0290	.5518	−7 23	68 52	.2088	.2071	−.0268	.5402
95	−6 48	70 53	.1940	.1927	−.0230	.5600	−5 51	69 06	.2091	.2080	−.0213	.5476
100	(−4 25)	71 08	.1928	(.1922)	(−.0148)	.5642	(−3 40)	69 20	.2085	(.2081)	(−.0133)	.5528
105	−1 18	71 12	.1926	.1926	−.0044	.5658	−0 56	69 20	.2093	.2093	−.0034	.5549
110	+1 34	71 08	.1933	.1932	+.0053	.5656	+1 43	69 11	.2096	.2095	+.0063	.5513
115	+4 02	70 41	.1968	.1963	+.0138	.5615	+3 57	68 53	.2100	.2095	+.0145	.5438
120	+6 05	70 09	.1997	.1986	+.0212	.5532	+5 51	68 27	.2131	.2120	+.0217	.5396
125	+7 41	69 40	.2017	.1999	+.0270	.5443	+7 23	67 50	.2183	.2165	+.0281	.5358
130	(+9 20)	69 01	.2026	(.1999)	(+.0329)	.5282	(+8 50)	66 56	.2227	(.2201)	(+.0342)	.5229
135	....	67 56	.2047	....	....	.5050	....	66 11	.2304	....	....	.5220
Long.	Parallel 49° North						Parallel 47° North					
°	° ′	° ′	c.g.s.	c.g.s.	c.g.s.	c.g.s.	° ′	° ′	c.g.s.	c.g.s.	c.g.s.	c.g.s.
60	−8 30	65 03	.2199	.2175	−.0325	.4727	−7 40	(62 40)	.2317	.2296	−.0309	(.4483)
65	−9 10	65 28	.2220	.2192	−.0354	.4864	−8 14	63 30	.2356	.2332	−.0337	.4725
70	−9 35	65 31	.2215	.2184	−.0369	.4864	−8 41	64 01	.2340	.2313	−.0353	.4801
75	−9 45	65 51	.2211	.2168	−.0374	.4931	−8 52	64 10	.2331	.2232	−.0359	.4815
80	−9 11	66 22	.2213	.2185	−.0353	.5057	−8 10	64 31	.2339	.2315	−.0332	.4908
85	−7 53	66 45	.2218	.2197	−.0304	.5162	−6 40	64 54	.2346	.2330	−.0272	.5008
90	(−6 25)	67 03	.2223	(.2209)	(−.0248)	.5250	(−5 30)	65 09	.2358	(.2347)	(−.0226)	.5091
95	−4 57	67 15	.2228	.2220	−.0192	.5313	−4 12	65 30	.2366	.2360	−.0173	.5192
100	−3 00	67 27	.2235	.2232	−.0117	.5382	−2 23	65 32	.2366	.2364	−.0098	.5200
105	−0 36	67 27	.2245	.2245	−.0024	.5406	−0 29	65 28	.2379	.2379	−.0020	.5212
110	+1 42	67 20	.2256	.2255	+.0067	.5402	+1 32	65 19	.2398	.2397	+.0064	.5218
115	+3 46	67 04	.2285	.2280	+.0150	.5401	+3 31	64 59	(.2430)	(.2425)	(+.0149)	(.5207)
120	+5 39	66 31	.2325	.2314	+.0229	.5351	+5 24	64 34	....	....	....	....
125	+7 11	65 57	.2369	.2350	+.0296	.5308	+7 09	64 07	....	....	....	....
130	(+8 40)	65 23	(.2430)	(.2402)	(+.0366)	(.5304)	(+8 50)	63 23	....	....	....	....
135	....	64 47	....	....	....	....	....	....	....	....	....	....
Long.	Parallel 45° North											
°	° ′	° ′	c.g.s.	c.g.s.	c.g.s.	c.g.s.						
60	(−6 55)	....	....	....	....	....						
65	(−7 25)	....	....	....	....	....						
70	−7 49	....	....	....	....	....						
75	−8 04	....	....	....	....	....						
80	−7 08	(62 20)	(.2500)	(.2481)	(−.0310)	(.4769)						
85	−5 24	(62 25)	(.2490)	(.2479)	(−.0234)	(.4766)						
90	(−4 25)	(62 40)	....	....	....	....						
95	(−3 30)	63 00	....	....	....	....						
100	−2 04	63 00	....	....	....	....						
105	−0 28	63 18	....	....	....	....						
110	+1 18	63 06	....	....	....	....						
115	+3 08	(62 47)	....	....	....	....						
120	+4 57	....	....	....	....	....						
125	+6 47	....	....	....	....	....						
130	+8 39	....	....	....	....	....						
135	....	....	....	....	....	....						

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THE ANOMALIES OF TERRESTRIAL MAGNETISM AND GRAVITY IN THE KURSK GOVERNMENT, RUSSIA.[1]

P. LASAREFF.

In a preceding article,[2] we have given the results of the operations carried out during 1919-1920 in connection with the work undertaken by the *Commission des Forces Productives de la Russie* cooperating with the Academy of Sciences, for investigating the anomalies of terrestrial magnetism and gravity in the Government of Kursk. The purpose of our note, presented at the Academy of Sciences, on May 2, 1923, was to summarize briefly the results obtained in 1921, 1922, and 1923.

As already indicated in the preceding note, a zone (the northern zone) of strong anomaly, consisting of a narrow strip of 2 to 3 kilometers, extends from the northwest towards the southeast and passes through the districts of Kursk, Stschigry and Tim for a distance of about 250 kilometers. It has a considerable maximum over an extent of 4 kilometers, the value of Z (vertical intensity) ranging from 1.6 to 1.9 gauss.

[1]Translated by Mr. H. D. Harradon from *Comptes Rendus de l'Académie des Sciences de Russie*, 1923, with some additions by the author.

[2]P. LASAREFF, Annexe aux procès-verbaux de l'Académie des Sciences de Russie, 1921, *Bull. de l'Acad.*, 1921, p. 81.

A point on this strip, the geographic coordinates of which are $\phi = 51° 50'$ N, $\lambda = 36° 52'$ E. of Gr. has been chosen by the Special Commission[3] for deep drilling operations (the depth proposed for the drilling being 250 meters).

The magnetic surveys of 1921, 1922 and 1923 have shown that the above-mentioned northern zone extends through the districts of Tim and Oskol towards the frontier of the Voronež Government and exhibits another maximum ($Z = 1.9$) near Oskol. This last maximum is formed by three zones of anomaly of very considerable intensity, proceeding from the fundamental zone of anomaly.

The study of gravity in the region of maximum anomaly has demonstrated that, in addition to a variation of Z, there exists a variation of gravity presenting a maximum which may coincide with the maximum of magnetic anomaly (district of Oskol, according to observations of M. P. Aksenov and M. A. Michajlov) or may be 200 meters distant from that of the magnetic anomaly (district of Stschigry, according to observations of M. A. Michajlov and Prof. M. P. Nikiforov).

The anomaly of gravity, exhibiting a very rapid variation towards the west, slowly diminishes towards the east. A detailed analysis of the field of magnetic and gravity anomaly shows, as already stated, that the causes of the anomaly of magnetism and those of gravity may be different.

Drilling at a point, mentioned above, shows that the masses near the surface with small density (2 to 2.5) give place at a depth of about 150 meters, to a layer of quartzite pierced by vertical and curved layers of magnetite. This mine layer having a density of 3.8, contains approximately 40 to 45 per cent of iron. The cores obtained by the drilling show a magnetic polarity with a south pole towards the surface of the Earth.

The thickness of quartzite and magnetite layers pierced by the drilling extends now to about 170 meters. Further operations should determine the total thickness of the iron ore.

It is very interesting to note here that the information regarding the depth of the mine layers published in 1921, is in perfect agreement with the recent observations obtained by the borings.

[3]This Commission includes a large number of Russian scientists and is directed by the following: Prof. J. Goubkin, president; Prof. P. Lasareff, member of the Academy of Sciences, vice-president and chief of magnetometric, gravimetric and geodetic operations; Prof. A. Archangelsky, chief of geological work, and M. A. Himmelfarb, engineer-in-charge of drilling operations and secretary of the Commission.

ON THE OBSERVATIONS OF EARTH POTENTIAL-GRADIENTS AT EBRO.

By S. Chafman and T. T. Whitehead.

1. In a recent paper[1] the writers have re-investigated the mathematical relations between the observed terrestrial magnetic variations and the external and internal (induced) magnetic fields which give rise to them. In the course of this paper we compared the diurnal variation of electric potential-gradient within the earth, given for Berlin, in arbitrary units, by Weinstein, with that derived from the potential of the field of the diurnal magnetic variations, as previously determined by one of us.[2] A moderate similarity in type was found; the question of agreement in absolute magnitude could not be tested, however, Weinstein's unit being unknown.

2. The recent appearance of Dr. Bauer's discussion of the measurements of earth potential-gradients at Ebro[3] affords the opportunity for further examination ot the question. It may be said at once that the results prove extremely puzzling. The observed potential-gradients are, as in Weinstein's case, nearly ot the type to be expected from the magnetic variations, but are five or six times as large in amplitude. As Dr. Bauer's tables refer to the means for groups of five magnetically quiet days, it seemed just possible that allowance for the factor 5 might have been overlooked, but on enquiry Dr. Bauer kindly confirmed our expectation that this was not the cause of the discrepancy.

3. The potential of the diurnal magnetic variations which was taken as the basis of comparison was the one already referred to in §1; it was derived from observations for the same two years (1902 and 1905) at observatories situated in both hemispheres. Ebro was not one of these observatories, and it is therefore of interest to compare the observed magnetic variation at Ebro with that resulting from this potential. The results for the vertical magnetic force, with which we are more immediately concerned, are given in Fig. 1, and indicate that the potential formula applies reasonably well to Ebro, and that the method of our joint paper is available for the calculation of the earth potential-gradients.

[1] Chapman, S., and T. T. Whitehead: The influence of electrically conducting material within the earth on various phenomena of terrestrial magnetism. *Cambridge, Trans. Phil. Soc.*, vol. xxii, June, 1922, pp. 463-482.

[2] Chapman, S.: The solar and lunar diurnal variations of terrestrial magnetism. *Phil. Trans. Roy. Soc.*, London, Series A., 1919, vol. 218, pp. 1-118.

[3] Bauer, L. A.: Some results of recent earth-current observations and relations with solar activity, terrestrial magnetism, and atmospheric electricity. *Terr. Mag.*, v. 27, 1922, pp. 1-30.

4. The diurnal variation of the N potential-gradient in the earth is given in formula 9.9 of our joint paper in a form which is equivalent to the following:

$$N \text{ (in millivolts per km.)} = \sum_{(p)} \frac{0.617\, p^2}{(p+1)\,(p+2)}\, Z_p \text{ (in } \gamma)$$

where Z_p denotes the harmonic component of frequency p in the vertical force diurnal variation (Z). The curve of N has been derived with the aid of this formula using the values of Z_p given in Table 9 of Dr. Bauer's paper on the Ebro observations. The resulting curve for N is given in Fig. 2, together with the observed curve as obtained by Dr. Bauer; but in order to make the two curves comparable, the former has been magnified in vertical scale five-fold. With this change, the two curves are in moderately good agreement, but the five-fold larger amplitude of the observed curve demands explanation.

5. The diurnal variation of the W potential-gradient can be calculated from formula 9.10 of our joint paper, which may be expressed in the form:

$$W \text{ (in millivolts per km.)} = \sum_{(p)} \frac{0.463\, \iota p^2}{(p+1)\,(p+2)} \cdot \frac{(p+1)\cos^2\theta - 1}{\sin\theta . \cos\theta}$$

Z_p (in γ) θ being the co-latitude. If θ for Ebro was 45°, instead of 40.°8, the factor $(p+1)\cos^2\theta - 1$ would vanish for the 24-hour component, and have the values 1/2, 3/2, and 5/2 for the components of respectively 12, 8, and 6 hour-periods. Thus in this and neighboring latitudes components of higher frequency are much magnified, relatively to their magnitudes in Z, in the W-component of the earth potential-gradient. This occurs also, but to a much smaller extent, in the N-component of the earth potential gradient. The fact that the calculated variation of W does not agree so well with the observed curve (Fig. 3) as was the case with N may be referred to this cause; the higher harmonics in the magnetic potential are perhaps hardly sufficiently well determined to bear the weight given them in this formula. As in Fig. 2, the scale of the calculated curves in Fig. 3 is five times that of the observed curve.

6. The above results show that there would be rough agreement between the predicted and observed values of the earth potential-gradient at Ebro if the scale difference of the observed and calculated curves could be accounted for. Having no practical experience in the measurement of earth potential-gradients, we do not venture to postulate any error in the scale value of the observations, but would draw attention to some other features of the Ebro results, as summarized by Dr. Bauer, which are difficult to account for. The diurnal variations of potential-gradient at Ebro and at Berlin show considerable agreement as to type, and if their amplitudes are comparable, it would seem that the arbitrary unit

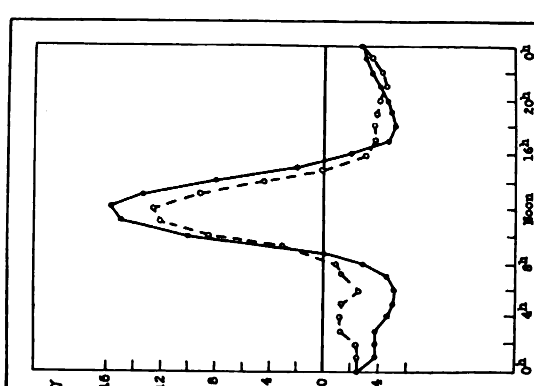

Fig. 1.—Diurnal Variation of Vertical Magnetic Force.

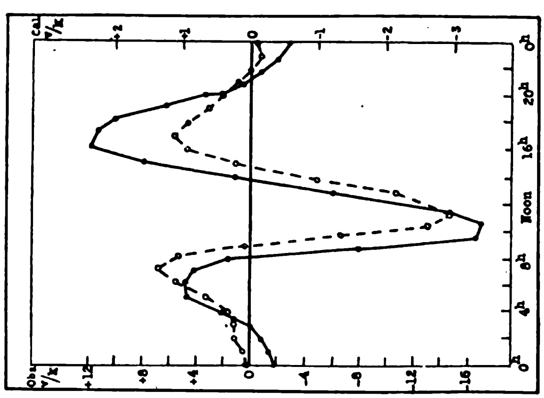

Fig. 2.—Diurnal Variation of the *N* Potential-Gradient of Earth Currents.

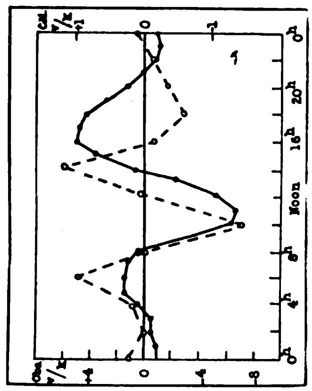

Fig. 3.—Diurnal Variation of the *W* Potential-Gradient of Earth Currents.

(Full Curves are observed ones, and broken curves, the computed ones.)

used by Weinstein represents about 1/40 millivolt per km. (Fig. 9 and Table 9 of Dr. Bauer's paper). But quite a different value of the unit is suggested by a comparison of the *average* values of the potential-gradients, viz., Weinstein's unit seems to be about 1 or 2 millivolts (*cf.* the ranges at the foot of Dr. Bauer's Table 6). Dr. Bauer remarks, however (p. 7), that "Weinstein himself does not appear to attach much value to his tabulated quantities for the constant currents." Nevertheless, the average potential-gradients at Ebro are surprisingly large as well as surprisingly variable from month to month, being of the order 1/3 volt per kilometre in the first half of the calendar year, and only about one-hundredth as great in some of the later months. It seems extraordinary that on magnetically quiet days there should exist earth potential-gradients as great as 1/3 volt per kilometre, which has hitherto been considered a highly exceptional value observed only during times of great magnetic disturbances.[4]

[4]Chree, C.: Earth Currents. *Encyc. Brit.*, 11th ed. vol. 8, 1910, pp. 813-816.

RELATIONS BETWEEN THE DIURNAL AND ANNUAL VARIATIONS OF EARTH CURRENTS, TERRESTRIAL MAGNETISM AND ATMOSPHERIC ELECTRICITY.

By Louis A. Bauer.

Abstract.—An investigation is made as to correlations in the diurnal and annual variations of earth-currents, with those of terrestrial magnestism and atmospheric potential-gradient, as based on the observations at the Ebro Observatory, Tortosa, Spain, for the magnetically-quiet days during the five-year period, 1914-1918.

It is found that the diurnal and annual variations of the horizontal components (X towards north, and Y towards east) of terrestrial magnetism are of such a character, quantitatively and qualitatively, as to indicate that only to a certain extent may they be the direct electromagnetic effects of the observed corresponding earth currents (W towards west, and N towards north). On the other hand there is a high probability that the observed earth-currents may be the combined result of a varying magnetic field and a varying electric field as indicated by the rate of variation in terrestrial magnetism and atmospheric electricity, during the day and year. The correlation between the variations of earth-currents and the rate of variation, or time-gradients, of the atmospheric potential-gradient is found to be even higher than that for the time-gradients of terrestrial magnetism, both as regards the diurnal variation and the annual variation.

1. The interesting attempt by S. Chapman and T. T. Whitehead[1] to reproduce theoretically the diurnal variation of earth currents, as observed at Berlin (1884-1887) and at the Ebro Observatory (1914-1918) prompts me to give a summary of some recent investigations which I have made bearing on the subject of earth-current variations and their possible causes. With respect to the last sentence of their second paragraph, let me say briefly that I have deduced the diurnal variation of the Ebro earth-current potential-gradients from the year 1922 alone and have found that the results are essentially the same as those obtained by me from the magnetically-calm days for the five-year period, 1914-1918.[2] Why the induced currents from the magnetic variations as derived by Chapman and Whitehead for Ebro are only about one-fifth of those found from observations, and the cause of the lack in phase agreement exhibited especially in the west-east component (see their Fig. 3) remain therefore to be explained. It is stated by them that the Ebro results "prove extremely puzzling." They have endeavored to derive the diurnal variation of the earth potential-gradients from the potential of the magnetic diurnal variation and the relations supposed to exist "between the observed terrestrial magnetic variations and the external and internal (induced) magnetic fields which give rise to them." It is

[1] *Terr. Mag.*, vol. 28 (1923), pp. 125-128.
[2] *Terr. Mag.*. vol. 27 (1922), pp. 12-25.

assumed by them that the diurnal variation of earth currents results solely from the currents induced by a varying magnetic potential; effects from a possible varying non-potential system, or from other causes, are at present not taken into account. It is not the purpose here to examine into the validity of the underlying assumptions, but rather to make a preliminary attempt to consider other possible causes which may assist in harmonizing theoretical results with the observational data.

2. The observed variations in earth currents during the day, year and sun-spot cycle, may be the combined result of a varying magnetic field and a varying electric field. Let us confine our attention at present to the results obtained from my discussion of the Ebro observations pertaining to terrestrial magnetism, earth currents, and atmospheric electricity, for the magnetically-calm days, 1914-1918. Tables 1 and 2 give, respectively, the results of the analyses of the diurnal and annual variations for the first two, or chief, terms of the Fourier series, as taken from my previous publication.[3] The notation used is as follows: Magnetic component, X, along a meridan, is taken positive towards true North, and, accordingly, a flow of positive electricity in the Earth's crust along a parallel of latitude, from east to west, is taken as a positive current W; magnetic component, Y, along a parallel of latitude, is taken positive towards true East, and, accordingly, a flow of positive electricity, from south to north, is taken as a positive current, N. A similar statement applies to the diurnal and annual variations. The data for the magnetic quantities are expressed in terms of $\gamma = 0.00001$ C.G.S., those for the earth-current gradients in millivolts per kilometer, designated by v/k = 0.001 V/k, volts per kilometer, and those for the atmospheric-electric gradients, P, by V/m, or volts per meter. P is plus throughout the period considered.

The quantities designated in Tables 1 and 2 by $\Delta X'$, $\Delta Y'$, $\Delta P'$, $\delta X'$, $\delta Y'$, $\delta P'$, are the first differential coefficients with respect to θ, or the first time-derivatives.

Chief aid was received in the computational work from Messrs. W. J. Peters, C. R. Duvall, C. C. Ennis, and Miss Emma L. Tibbetts.

DIURNAL VARIATION OF EARTH CURRENTS.

3. Examining first the ratio, c_2/c_1, of the amplitudes of the 12-hour and 24-hour terms, as given in Table 1, it will be seen that the value for the magnetic derivative, $\Delta Y'$, as also that for the atmospheric-electric derivative, $\Delta P'$, agree closely with the value for the earth-current gradients, ΔN and ΔW; the average value of this ratio is 1.7, hence, the amplitude of the 12-hour wave is nearly twice that of the 24-hour wave.

[3] *Terr. Mag.*, vol. 27 (1922), Table 9, p. 21, and Table 7, p. 11.

TABLE 1.—*Results of Fourier analysis of diurnal variation* ($\triangle$) *of magnetic components* (X, Y), *earth-current gradients* (N, W), *and of atmospheric potential-gradient* (P) *at the Ebro Observatory for the magnetically-calm days, 1914-1918.*

$\triangle = c_1 \sin(\theta + \phi_1) + c_2 \sin(2\theta + \phi_2) + \ldots\ldots$; θ is counted from 0^h, midnight, G.M.T., at the rate of 15° per hour.

Quant.	$\triangle X$	$\triangle Y$	$\triangle P$	$\triangle Y'$	$\triangle N$	$\triangle P'$	$\triangle X'$	$\triangle W$
	γ	γ	V/m	γ/θ	v/k	V/m	γ/θ	v/k
c_1	4.1	12.8	19.4	12.8	5.3	19.4	4.1	2.1
c_2	1.6	11.4	15.8	22.8	9.0	31.5	3.2	3.6
c_2/c_1	0.4	0.9	0.8	1.8	1.7	1.6	0.8	1.7
	°	°	°	°	°	°	°	°
ϕ_1	99	35	210	125	141	300	189	151
ϕ_2	236	220	196	310	296	286	326	297

TABLE 2.—*Results of Fourier analysis of annual variations* (δ) *of magnetic components, earth-current gradients and of atmospheric potential-gradient at the Ebro Observatory for the magnetically-calm days, 1914-1918.*

$\delta = c_1 \sin(\theta + \phi_1) + c_2 \sin(2\theta + \phi_2) + \ldots\ldots$; θ is counted from midnight of December 31 at the rate of 30° per average month.

Quant.	δX	δY	δP	$\delta Y'$	δN	$\delta P'$	$\delta X'$	δW
	γ	γ	V/m	γ/θ	v/k	V/m	γ/θ	v/k
c_1	13.4	3.7	18.4	3.7	169	18.4	13.4	73
c_2	0.4	3.2	4.8	6.4	59	9.6	0.8	27
c_2/c_1	0.0	0.9	0.3	1.7	0.3	0.5	0.1	0.4
	°	°	°	°	°	°	°	°
ϕ_1	279	152	71	242	146	161	9	148
ϕ_2	48	245	237	335	269	327	138	277

The phase angles, ϕ_1, of the 24-hour wave, are in fair agreement for $\triangle Y'$ and $\triangle N$, also for $\triangle P'$, if we take the *supplement* 120°, instead of 300°, which implies reversing the signs of $\triangle P$ for the 24-hour term. The values of ϕ_1 for $\triangle X'$ and $\triangle W$ are somewhat alike; however, the amplitude-ratio, c_2/c_1, for $\triangle X$ is only half that for $\triangle W$.

Turning next to the phase angles, ϕ_2, of the 12-hour or principal wave, a general agreement is found for the quantities $\triangle Y'$, $\triangle N$, $\triangle P'$, $\triangle X'$, and $\triangle W$; the value of ϕ_2 for $\triangle X'$ departs most from the corresponding earth-current gradient, $\triangle W$.

4. Table 3 contains the computed hourly values of the various quantities, as derived from the first two terms of the Fourier series given in Table 1. The hourly differences, $\triangle$, are the algebraic differences obtained by subtracting from the hourly value of the particular element considered the mean value of the element for the day. Instead of the hourly values of the derivatives, $\triangle X'$, $\triangle Y'$, and $\triangle P'$, the differentials DX, DY, DP, which are the

hourly differences centering at the whole hour, are given. Thus, for example, DY_{12} opposite 1^h, $+0.2\gamma$, is the algebraic difference (Y_{12} at $1.^h5$ − Y_{12} at $0.^h5$); similarly for the other quantities. If it is desired to obtain the derivatives, it is only necessary to divide the tabulated differentials by $15 \times \sin 1° = 0.262$, since one hour corresponds to 15°. "A. D." at the bottom of the table stands for "average departure," that is, the mean value of the quantity in the respective column, irrespective of sign.

The quantities in the formulæ, (1) to (16), are indicated by the subscript 1 for the 24-hour wave, by the subscript 2 for the 12-hour wave, and by the subscript 12 for the combined waves. The quantities in columns 2 and 5 of Table 3 have been derived from those in column 2*a* with the aid of the azimuthal quantity, 21°.3, which appears in formulæ (15) and (16).

Formulæ (1) to (16) have been established by the method of least squares with the aid of the quantities obtained from the data in Tables 1 and 3.

TABLE 3.—*Diurnal variations of earth-current gradients and of differential changes in magnetic components and atmospheric potential-gradients at the Ebro Observatory for the magnetically-calm days, 1914-1918, 24-hour wave and 12-hour wave combined.*

G.M.T.	1. $\triangle W_{12}$	2a DP_{12}	2. $DP_{12}(W)$	3. DX_{12}	4. $\triangle N_{12}$	5. $DP_{12}(N)$	6. DY_{12}
h	v/k	V/m	V/m	γ	v/k	V/m	γ
1	−1.5	− 2.0	−0.7	−0.5	− 2.9	− 1.9	+0.2
2	−0.2	+ 0.7	+0.2	−0.3	+ 0.1	+ 0.7	+2.4
3	+1.1	+ 3.7	+1.3	−0.2	+ 3.3	+ 3.5	+4.4
4	+2.0	+ 5.9	+2.1	−0.2	+ 5.5	+ 5.5	+5.3
5	+2.1	+ 6.7	+2.4	−0.4	+ 5.8	+ 6.3	+4.8
6	+1.4	+ 5.3	+1.9	−0.6	+ 3.9	+ 5.0	+2.7
7	0.0	+ 2.0	+0.7	−0.9	+ 0.2	+ 1.9	−0.6
8	−1.9	− 2.5	−0.9	−1.2	− 4.6	− 2.3	−4.0
9	−3.7	− 7.2	−2.6	−1.3	− 9.2	− 6.7	−7.1
10	−4.9	−11.0	−3.9	−1.2	−12.4	−10.3	−8.9
11	−5.0	−12.9	−4.6	−0.8	−13.3	−12.1	−9.0
12	−4.2	−12.2	−4.3	−0.3	−11.4	−11.4	−7.4
13	−2.5	− 9.2	−3.3	+0.3	− 7.3	− 8.6	−4.2
14	−0.2	− 4.5	−1.6	+1.1	− 1.5	− 4.2	−0.4
15	+2.3	+ 0.9	+0.3	+1.6	+ 4.5	+ 0.8	+3.2
16	+4.2	+ 5.9	+2.1	+1.8	+ 9.3	+ 5.5	+5.9
17	+5.1	+ 9.3	+3.3	+1.8	+12.2	+ 8.7	+7.0
18	+5.0	+10.3	+3.7	+1.6	+12.3	+ 9.6	+6.5
19	+4.0	+ 9.2	+3.3	+1.1	+10.0	+ 8.6	+4.6
20	+2.3	+ 6.3	+2.2	+0.4	+ 6.0	+ 5.9	+2.0
21	+0.3	+ 2.6	+0.9	−0.1	+ 1.4	+ 2.4	−0.5
22	−1.3	− 0.8	−0.3	−0.4	− 2.4	− 0.7	−2.3
23	−2.2	− 3.1	−1.1	−0.6	− 4.7	− 2.9	−2.8
24	−2.2	− 3.4	−1.2	−0.7	− 4.8	− 3.2	−1.8
A. D.	2.5	5.7	2.0	0.8	6.2	5.4	4.1

5. *Hypothesis a.—The magnetic diurnal variations are caused by earth-current diurnal variations.*

$$\Delta Y_1 = -\ 0.68\ \Delta N_1; \qquad r = -0.29 \qquad (1)$$
$$\Delta X_1 = +\ 1.22\ \Delta W_1; \qquad r = +0.61 \qquad (2)$$
$$\Delta Y_2 = +\ 0.31\ \Delta N_2; \qquad r = +0.25 \qquad (3)$$
$$\Delta X_2 = +\ 0.21\ \Delta W_2; \qquad r = +0.48 \qquad (4)$$

We see that not only do the factors which express the numerical relationships between the magnetic and electric diurnal variations differ among themselves, but they are even of reversed signs for the 24-hour wave. It is further seen that the maximum value of r is 0.61, namely for ΔX_1 and ΔW_1, and that, in general, the correlation between ΔY and ΔN is less than 0.30. *The conclusion must apparently be drawn that only in a very minor degree may the observed magnetic diurnal variation, ΔY, be caused by the observed earth-current diurnal variation, ΔN; however, the observed magnetic diurnal variation, ΔX, may be caused to a considerable extent by the observed earth-current diurnal variation, ΔW.*[4]

6. *Hypothesis b.—The earth-current diurnal variations are caused by rate of variation, or time-gradients, of terrestrial magnetism during the day.* (*Electromagnetic Induction.*)

$$\Delta N_1 = +1.53\ DY_1 \quad ; \qquad r = +0.96 \qquad (5)$$
$$\Delta W_1 = +1.52\ DX_1 \quad ; \qquad r = +0.79 \qquad (6)$$
$$\Delta N_2 = +1.46\ DY_2 \quad ; \qquad r = +0.97 \qquad (7)$$
$$\Delta W_2 = +3.84\ DX_2 \quad ; \qquad r = +0.88 \qquad (8)$$
$$\Delta N_{12} = +1.48\ (DY_1 + DY_2) \quad ; \qquad r = +0.96 \qquad (9)$$
$$\Delta W_{12} = +2.38\ (DX_1 + DX_2) \quad ; \qquad r = +0.77 \qquad (10)$$

For this hypothesis, it is seen that the numerical factors are practically the same throughout, excepting those for (8) and (10). The sign of the factor is positive throughout. The value of the correlation coefficient is over 0.95 for ΔN and ΔY, and while it is lower for ΔW and ΔX, it falls between 0.77 and 0.88. *The conclusion to be drawn apparently is that it is highly probable that earth-current diurnal variations are effects resulting from, or associated with, the fluctuating Earth's magnetic field during the day.* However, Chapman and Whitehead, as stated in §1, have not yet been able to obtain entirely satisfactory agreement between the gradients theoretically deduced on this hypothesis and the observed gradients.

[If account be taken of a lag, averaging about one hour, in the earth-current gradients, ΔN and ΔW, with respect to their possible primary causes, DY and DX, then the correlation coefficient for (9) is +0.93 and for (10) +0.88.]

7. *Hypothesis c.—The earth-current diurnal variations are in correspondence with the rate of variation, or time-gradients, of atmospheric potential-gradient during the day.* (*Varying Electric Field.*)

[4] See the similar conclusion reached by L. STEINER, *Terr. Mag.*, vol. 13 (1908), p. 62.

$$\Delta N_1 = 1.04 \cos 19.^\circ 6\,(-DP_1) = 1.04\,.DP_1(N)\;;\; r = +0.93 \qquad (11)$$
$$\Delta W_1 = 1.04 \sin 19.6\,(-DP_1) = 1.04\,.DP_1(W)\;;\; r = +0.85 \qquad (12)$$
$$\Delta N_2 = 1.17 \cos 21.9\, DP_2 = 1.17\,.DP_2(N)\;;\; r = +0.99 \qquad (13)$$
$$\Delta W_2 = 1.17 \sin 21.9\, DP_2 = 1.17\,.DP_2(W)\;;\; r = +0.97 \qquad (14)$$
$$\Delta N_{12} = 1.14 \cos 21.3\,(DP_2 - DP_1) = 1.14\,.DP_{12}(N)\;;\; r = +0.97 \qquad (15)$$
$$\Delta W_{12} = 1.14 \sin 21.3\,(DP_2 - DP_1) = 1.14\,.DP_{12}(W)\;;\; r = +0.95 \qquad (16)$$

It is seen that for this hypothesis the numerical factors are practically the same throughout, as also the azimuthal quantities (19°.6; 21°.9; 21°.3), provided that the original signs of DP_1 be reversed. The average correlation coefficient, 0.95, is even higher than that (0.89) for hypothesis *b*. In view of the different origins of the 24-hour wave and the 12-hour wave in atmospheric electricity, the former progressing chiefly according to universal time and the latter chiefly according to local time, it may not be surprising that in equations (11) and (12) it was necessary to use $-DP_1$ instead of $+DP_1$. (While DP_1 varies from hour to hour chiefly according to universal time, its magnitude at the same absolute time at various stations may be different.) The azimuthal quantity, about 21° for the two waves, is approximately the bearing, 24.°5 west of true north, at the Ebro Observatory, of the North Magnetic Pole; the corresponding bearing for the north end of the magnetic axis of the Earth's internal uniform magnetic field is 15°.0 west of north, and that for the Earth's external uniform magnetic field is 14°.3 west of north. It would seem as though associated with changes in atmospheric-electric potential there are electric currents which flow approximately along the magnetic meridians in the atmosphere and in the Earth's crust, the average direction of flow in the Earth's crust being in opposite directions for the diurnal and semi-diurnal waves. A discussion of the precise *modus operandi* had best be deferred at present, pending the completion of other related investigations. *It must be concluded apparently that a very close relationship exists between earth-current diurnal variations and time-gradients of the atmospheric-electric potential during the day. It would seem that the relationship between earth currents and atmospheric electricity is even closer than between earth currents and terrestrial magnetism.*

As a result of the relationships given in §§6 and 7, it follows that the correlation between the time-gradients of the diurnal variations of terrestrial magnetism and of the atmospheric potential-gradient is very high (from 0.8 to 1.0).

For all the relations given in §§6 to 7, the correlation coefficient is generally less for the ΔX magnetic component than for the ΔY magnetic component, possibly because of other effects entering, as for example from *vertical* electric currents, or from an equivalent cause.

ANNUAL VARIATION.

8. The explanations given in §4 with regard to the diurnal-variation quantities likewise apply to the annual-variation quantities (Tables 2 and 4) by making the appropriate substitutions. Instead of the monthly values of the derivatives, $\delta X'$, $\delta Y'$, and $\delta P'$, the differential quantities dX, dY, dP, which are the monthly differences centering at the middle of the month, are given in Table 4 and used in formulae (21) to (32). To obtain the derivates it is only necessary to divide the differential quantities by $30 \times \sin 1° = 0.524$.

The *amplitude ratios*, c_2/c_1, given in Table 2, are in good agreement for δN, $\delta P'$, and δW; those for $\delta Y'$ and δN differ markedly. The *phase angles*, ϕ_1, are in fair agreement only for δY, δN, $\delta P'$ and δW. The *phase angles*, ϕ_2, are in general agreement for all the quantities, except for δX and $\delta X'$.

Formulæ (17) to (32) have been established by the method of least squares with the aid of the quantities obtained from the data in Tables 2 and 4.

9. *Hypothesis a.—The magnetic annual variations are caused by the earth-current annual variations.*

$$\delta Y_1 = +0.022\,\delta N_1 \;; \qquad r = +0.99 \tag{17}$$
$$\delta X_1 = -0.120\,\delta W_1 \;; \qquad r = -0.65 \tag{18}$$
$$\delta Y_2 = +0.049\,\delta N_2 \;; \qquad r = +0.91 \tag{19}$$
$$\delta X_2 = -0.010\,\delta W_2 \;; \qquad r = -0.61 \tag{20}$$

It is seen that the numerical factors for δY and δX are of opposite signs for both the 12-month wave and the 6-month wave, and furthermore differ considerably among themselves; both of these facts are difficult to reconcile with the hypothesis that the magnetic variations are the electromagnetic effects of earth-current variations. Yet the correlation coefficients are high, especially for δY and δN, and we may have an indication here that in the annual variation there is another system of currents (for example, vertical currents) to be considered in addition to possible currents flowing parallel to the Earth's surface. Accordingly, it would seem best at present to leave open hypothesis *a* for further subsequent examination.

TABLE 4.—*Annual variations of earth-current gradients and of monthly differential changes in magnetic components and atmospheric-potential gradients at the Ebro Observatory for the magnetically-calm days, 1914-1918, 12-month wave and 6-month wave combined.*

Month	1. δW_{12}	2a. dP_{12}	2. $dP_{12}(W)$	3. dX_{12}	4. δN_{12}	5. $dP_{12}(N)$	6. dY_{12}
	v/k	V/m	V/m	γ	v/k	V/m	γ
Jan.	0	+ 0.4	+0.2	+2.7	+ 3	+ 0.4	−1.4
Feb.	−13	− 0.1	0.0	+4.7	− 33	− 0.1	+1.1
Mar.	−26	− 3.0	−1.2	+5.8	− 60	− 2.7	+1.2
Apr.	−49	− 8.3	−3.4	+5.6	−108	− 7.6	−0.1
May	−74	−11.4	−4.6	+4.0	−165	−10.4	−2.2
Jun.	−77	− 8.8	−3.6	+1.0	−179	− 8.0	−1.1
Jul.	−42	− 0.8	−0.3	−2.5	−107	− 0.7	+2.0
Aug.	+19	+ 7.5	+3.0	−5.3	+ 31	+ 6.9	+4.3
Sep.	+74	+11.0	+4.5	−6.6	+162	+10.1	+3.6
Oct.	+91	+ 8.7	+3.5	−5.8	+212	+ 8.0	+0.1
Nov.	+68	+ 4.0	+1.6	−3.4	+167	+ 3.7	−3.2
Dec.	+29	+ 0.8	+0.3	−0.2	+ 77	+ 0.7	−3.7
A. D.	47	5.4	2.2	4.0	109	4.9	2.0

10. *Hypothesis b.—The earth-current annual variations are caused by the rate of variation, or time-gradients, of terrestrial magnetism during the year. (Electromagnetic Induction.)*

$$\delta N_1 = -\ 9.77\, dY_1 \quad ; \quad r = -0.11 \qquad (21)$$
$$\delta W_1 = -\ 7.84\, dX_1 \quad ; \quad r = -0.75 \qquad (22)$$
$$\delta N_2 = +\ 7.08\, dY_2 \quad ; \quad r = +0.40 \qquad (23)$$
$$\delta W_2 = -47.18\, dX_2 \quad ; \quad r = -0.78 \qquad (24)$$
$$\delta N_{12} = +\ 2.32\, (dY_1 + dY_2) \quad ; \quad r = +0.04 \qquad (25)$$
$$\delta W_{12} = -\ 8.99\, (dX_1 + dX_2) \quad ; \quad r = -0.73 \qquad (26)$$

These formulæ show that not only do the numerical factors vary considerably among themselves, both as to magnitude and sign, but the correlation coefficents likewise. While the correlation coefficient between the δN and dY quantities is invariably small and variable in sign, that between the δW and $(-dX)$ quantities is on the average 0.75.

11. *Hypothesis c.—The earth-current annual variations are in correspondence with the rate of variation, or time-gradients, of atmospheric potential-gradient during the year. (Varying Electric Field.)*

$$\delta N_1 = 20.00 \cos 21°.6\, dP_1 = 20.00.dP_1\,(N) \quad ; \quad r = +0.96 \qquad (27)$$
$$\delta W_1 = 20.00 \sin 21.6\, dP_1 = 20.00.dP_1\,(W) \quad ; \quad r = +0.97 \qquad (28)$$
$$\delta N_2 = 7.08 \cos 28.5\, dP_2 = 7.08.dP_2\,(N) \quad ; \quad r = +0.53 \qquad (29)$$
$$\delta W_2 = 7.08 \sin 28.5\, dP_2 = 7.08.dP_2\,(W) \quad ; \quad r = +0.64 \qquad (30)$$
$$\delta N_{12} = 18.13 \cos 23°.9\, (dP_1+dP_2) = 18.13.dP_{12}\,(N) \quad ; \quad r = +0.89 \qquad (31)$$
$$\delta W_{12} = 18.13 \sin 23.9\, (dP_1+dP_2) = 18.13.dP_{12}\,(W) \quad ; \quad r = +0.91 \qquad (32)$$

These formulæ show general consistency, and the correlation coefficients range from 0.53 to 0.97, the average value being 0.82. It is a matter of interest also that the azimuthal quantities (21°.6, 28°.5, 23°.9) as obtained from the annual variations are practically

the same as those obtained from the diurnal variations. *It would seem that we are justified in concluding that there is a very close relationship between the annual variations of earth-currents and the time-gradients of the atmospheric potential-gradient during the year.*

EXPLANATIONS OF DIAGRAMS.

12. Fig. 1 shows a graphical qualitative comparison between the *diurnal variations* of the earth-current potential-gradients (*W* and *N*) and the hourly differential changes, or time-gradients per hour, of the horizontal magnetic components (*X* and *Y*) and of the components (*W* and *N*) of the atmospheric-potential gradient (*P*) as obtained from Table 3. No quantitative reduction of the curves to a common basis, or to the same units, has at present been attempted, the main purpose being a comparison as to phase agreement and general course of the various curves.

It will be seen that for both sets of curves, the upper (Nos. 1, 2 and 3) and the lower (Nos. 4, 5 and 6), the curves obtained from rate of variation in atmospheric potential-gradient during the day (Nos. 2 and 5) agree, in general, better with the corresponding earth-current curves (Nos. 1 and 4) than do those (Nos. 3 and 6) obtained from the rate of variation in the horizontal components of terrestrial magnetism during the day. Possibly the lag in phase shown by Curves Nos. 1 and 2 with respect to No. 3, and by Curves 4 and 5 with respect to No. 6 may prove significant in determining which phenomenon is cause and which is effect.

13. Fig. 2 shows a similar comparison to that in Fig. 1, with regard to the *annual variation* of the earth-current potential-gradients (*W* and *N*) and the monthly differential changes, or time-gradients per month, of the horizontal magnetic components (*X* and *Y*) and of the components (*W* and *N*) of the atmospheric potential-gradient (*P*) as obtained from Table 4. Again, no quantitative reduction of the curves to a common basis, or to the same units, has at present been attempted, the main purpose being a qualitative comparison as to phase agreement and general course of the various curves.

It appears that for both sets of curves, the upper (Nos. 1, 2 and 3) and the lower (Nos. 4, 5 and 6), the curves obtained from the rate of variation of the atmospheric potential-gradient during the year (Nos. 2 and 5), agree better with the corresponding earth-current curves (Nos. 1 and 4) than do those (Nos. 3 and 6) obtained from the rate of variation in the horizontal components of terrestrial magnetism during the year. A study of the phase-displacements of the various curves with the aid of additional data may prove of importance.

SUN-SPOT CYCLE VARIATION.

14. A close correspondence is found to have existed between variations in solar activity, earth currents and the atmospheric potential-gradient at the Ebro Observatory during the past sun-spot cycle. This matter will be treated in a paper dealing with the correlations between solar activity and atmospheric-electric phenomena, which was to have appeared in the present issue of this

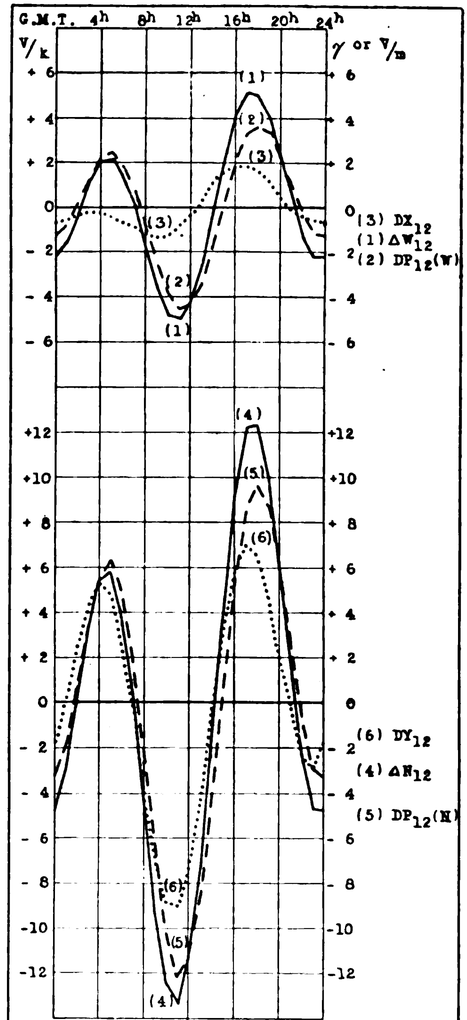

Fig. 1.—Qualitative Comparison Between Diurnal Variations of Earth Current Potential-Gradients and Hourly Rate of Changes of Terrestrial Magnetism and of the Atmospheric Potential-Gradient at the Ebro Observatory for the Magnetically-Calm Days, 1914-1918. (See § 12.)

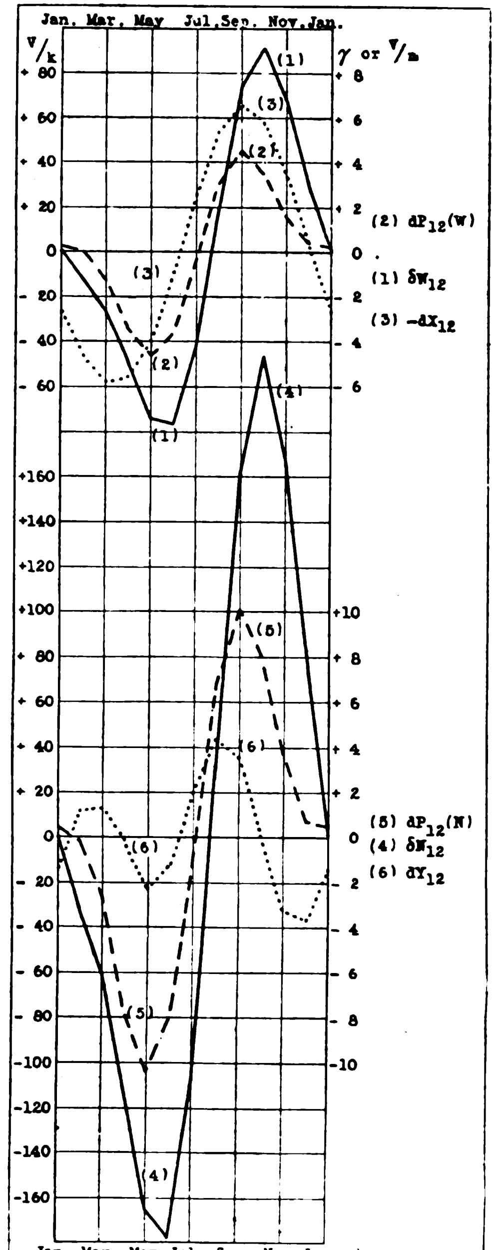

Fig. 2.—Qualitative Comparison Between Annual Variations. (See § 13.)

Journal but whose publication has been deferred until the next issue, pending receipt of certain data from European observatories.

CHIEF CONCLUSIONS.

15. Referring to the observations of earth currents, terrestrial magnetism and atmospheric electricity at the Ebro Observatory, Tortosa, Spain, for the magnetically-calm days during the five-year period 1914-1918, and considering for the present only the first two, or chief, periodic terms of the Fourier series, the following main conclusions are reached:

a. The diurnal and annual variations of the Earth's magnetic field seem to be the direct electromagnetic effects only to a certain extent of the observed diurnal and annual variations of electric currents flowing in the Earth's crust.

b. It is highly probable that both the meridional and the latitudinal components of the diurnal variation of earth currents are effects resulting from, or associated with, the fluctuating Earth's magnetic field during the day.

c. A very close relationship exists between earth-current diurnal variations and the rate of variation of the atmospheric potential-gradient during the day.

d. The annual variations of earth currents may be attributed, apparently, to a certain extent to the rate of variation of the Earth's magnetic field during the year.

e. There is a very close relationship between the annual variations of earth-currents and the gradients of change of the atmospheric potential-gradient during the year.

SUBSEQUENT INVESTIGATIONS.

16. Since formulæ (17) to (32) were established it became possible, with the aid of the results obtained from the investigation in §14, to make another determination of the annual variations of the earth-current gradients and of the atmospheric potential-gradient at the Ebro Observatory, not only by reducing the observed quantities for the period 1914-1918 to the same epoch, 1916.5, but also to the mean sun-spot number, 59.7, for that period. While the numerical factors appearing in formulæ (17) to (32) are slightly changed, if the revised annual-variation quantities are used, none of the conclusions already drawn are found to require any modifications.

A future paper will include also a consideration of the third and fourth terms of the Fourier series, both as regards the diurnal and the annual variations, will contain a discussion of the available data from stations other than the Ebro Observatory, and will treat also the available results from other than magnetically-calm days. The main purpose of the present paper has been to obtain relations which may be tested with the aid of further data.

(*To be Continued.*)

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON.

LETTERS TO EDITOR

ON THE MAGNETIC ANOMALY IN POLAND.

When I began magnetic investigations in Polish territory in 1910, I could not be guided in any way by previous surveys, because they were mostly disconnected and not sufficiently worked out.

From separate investigations conducted here and there at different times, we could only estimate with some approximation the annual changes. As a fundamental distance between observation points, I took 40 kilometers, though realizing that later on it would be necessary to diminish this; however, when it was possible (the facility of communication had to be thought of and it is to be remembered that I was doing this at the time of Russian rule), I tried to use also smaller distances, about half as large. The above explains why the distribution of my observation points is not uniform over the whole of Congress (Russian) Poland which has been examined. But, thanks to it, I may draw with still greater assurance conclusions as to the abnormal course of isomagnetic lines, and form other plans as to further investigations. Figs. 1, 2, and 3 show the observation-points mentioned for the years 1910-1913, together with the respective values of *D*, *H*, and *I*, all reduced to average annual value of 1912, and so they are comparable with each other.

Thus from the observations already made we can judge as to the abnormal course of the isomagnetic lines over the territory of Poland; further investigations will bring more detailed information about the anomaly. As we can note, it is not of large magnitude, but it is to be expected, that isomagnetic lines, which only later on it will be possible to determine, will be in certain places closed, embracing certain maxima and minima. It is interesting and also in accordance with the above, that in Western and Eastern Russia, and in the territory immediately adjoining that which has been examined by me, the abnormal course of isogones had also been confirmed, as is shown by the report of Adolf Schmidt on results of investigations conducted in the years 1905-1908.

St. Kalinowski.

Observatoire Magnétique,
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RESULTS OF MAGNETIC SURVEY OF POLAND FOR 1912.5.

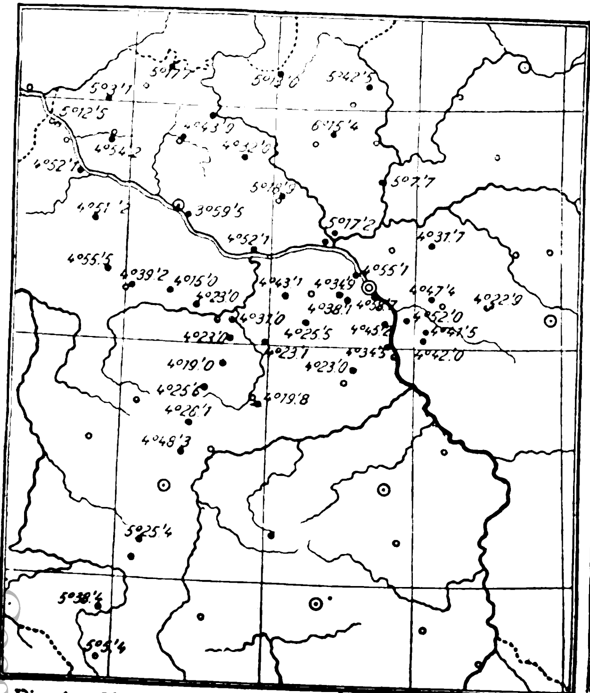

Fig. 1.—Values of Magnetic Declination.

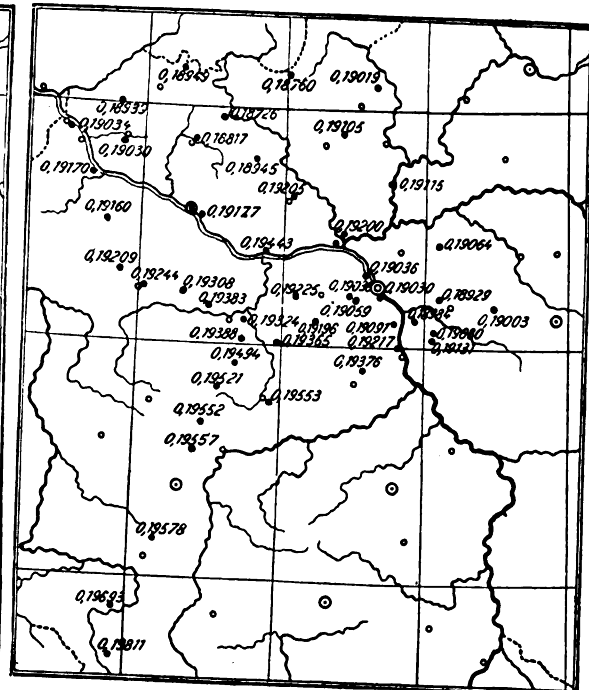

Fig. 2.—Values of Horizontal Intensity.

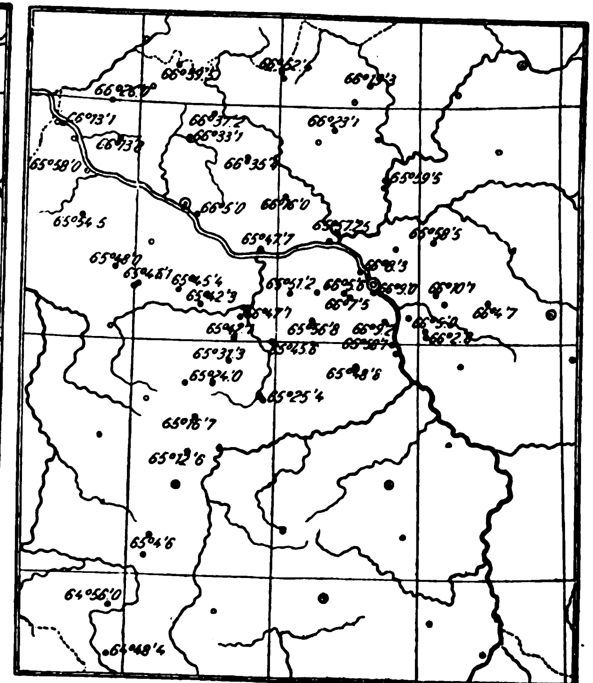

Fig. 3.—Values of Magnetic Inclination.

REGARDING MAGNETIC WORK IN NORWAY.

I have the pleasure to give you the following information as to the present magnetic work in this country.

The *Haldde Observatory* is regularly carrying on magnetic observations and photographic registrations, but no publication of the results has thus far appeared, and moreover I fear that the absolute measurements and the determinations of the constants of the instruments, as well as the value of the base-line of the registration curves, have not been made regularly and with the accuracy demanded in modern magnetic work. The registration instruments used at Haldde are of the Eschenhagen type. As far as I know they have a double set of such instruments, but none for eye readings. For the absolute measurements the Haldde Observatory possesses an instrument from the firm Tesdorpf in Stuttgart; this instrument is designed, not as a first-class station instrument, but for survey work.

Beside the observations at Haldde regular magnetic registrations (with one set of apparatus of the Eschenhagen type) are carried on at *Dombaas*, a place on the southern slope of the Dovre mountain between Trondhjem and Kristiania. As far as I know, however, no absolute measurements have ever been made at this place and the curves obtained have consequently only a limited interest.

On *Spitzbergen and the island of Jan Mayen* magnetic registrations have occasionally been made by expeditions from the Geophysical Institute of Tromsö, but with quite unsatisfactory absolute measurements, and up to the present time no results from the magnetic work of these different stations have been published.

We have also a long series of unpublished observations at the old magnetic observatory connected with the Astronomic Observatory of the University of *Kristiania*. This magnetic observatory was founded by Hansteen, and for about a hundred years ocular observations of declination and horizontal intensity have been made three times every day. Owing to the electric tramways, however, which since about the year 1900 have passed this observatory at a distance of not more that 200 meters, the observations during the last 25 years may be of dimished value, but they have been continued in the manner originally established. At the request of the new director of the Astronomic Observatory, Prof. Schroeter, I am having all these observations more closely examined, and we hope eventually to get them published if they shall prove to be worth publication.

The instruments used at Kristiania are for the horizontal intensity a large bar magnet (about 1 meter long), bifilarly suspended, and hanging in the central dome of the old observatory, and for the declination a unifilar magnetometer from Elliott Bros. This last instrument has also been used for the absolute measurements of declination and horizontal intensity during the last 40 years. For the determinations of inclination, a Dover inclinatorium has been used.

As will appear from the facts above mentioned some magnetic work is being done in Norway. I am now trying to get the whole work conducted after more systematic lines The first thing to be done will be to get exact and reliable absolute determinations of the magnetic constants at least at one station. For this end I have planned a new magnetic observatory chiefly for absolute measurements and comparisons of instruments at *Trondhjem*, this being the most central place of the country for such work. The instrumental outfit of this observatory will be a new magnetic theodolite from Bamberg in Berlin, which instrument has been bought upon recommendation by Prof. Schmidt of Potsdam, and for the observations of variations in D and H, magnetographs of the Eschenhagen type with all modern improvements and arranged both for registration and ocular reading with telescope and scale. Moreover I intend to buy an earth inductor as soon as funds are available. From the preliminary examinations of the Bamberg theodolite at the Rude Skov Observatory near Copenhagen this summer I fear, however, that the instrument is not made of absolutely nonmagnetic materials. The final examination of the instrument and determination of its constants cannot be done before next spring. As soon as this work has been performed all the other instruments for absolute measurements which we possess and intend to use, will be compared at the new observatory and all the base values will be determined at the magnetic stations where registrations are carried on.

At the same time I hope to start and carry on a regular *magnetic survey of Norway;* up to the present time no such survey has been made. Twenty years ago, in 1904 and 1905, I made some preliminary observations with the instrument now at Haldde, as a beginning of a complete survey, but in the meantime other duties have prevented me from fulfilling the task. The results of the said observations have been published in Archiv. f. Mathematik og Naturvidenskab, 1906, but are of little value. Other survey-measurements were performed by the late director Aksel Steen in the year 1902 with the instrument used by Capt. Amundsen on his expedition with the "Gjöa" to the magnetic pole.

For the survey now planned I have just ordered an apparatus of the Carnegie Institution type, together with the similar instruments ordered by Sweden and Denmark, and I hope that this survey may be carried on in cooperation with similar work in the other Scandinavian countries.

PROF. SEM SAELAND,
Director of the Physical Institute of the University of Christiania.

PROVISIONAL SUN-SPOT NUMBERS FOR JULY TO DECEMBER, 1923.

Day	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	18	0	11	8	..	..
2	17	0	13	10	28	0
3	8	0	17	7	24	..
4	0	0	23	7	..	0
5	0	0	19	..	27	0?
6	0	0	16	0	..	..
7	0	0	19	0	..	0?
8	0	0	33	..	..	0
9	0	0	22	..	10	0
10	0	0	23	8	7?	0
11	0	0	10	8	..	..
12	0	0	10	7	..	..
13	0	0	8	..	7	..
14	0	0	10	7	7	..
15	0	0	..	10	7	..
16	0	0	9	8	..	0
17	0	0	14	10	0	0
18	..	0	..	8	0	0
19	0	0	7	7	0	..
20	0	7	..	..	0	0?
21	0	8	0	7	0	..
22	8	..	0	..	0	..
23	7	0	0	27	0	..
24	7	0	7	..	..	..
25	7	0	11	32	..	16
26	7	0	14	22	..	..
27	0	0	21	21	..	..
28	0	0	19	16	..	0?
29	10	0	19	13	7	0
30	14	0	15	13	0	..
31	7	..		19		..
Mean	3.7	0.5	13.7	11.5	7.3	1.1

Mean number for the year 1923, $R=5.5$

Zürich, Sept. 30 and Dec. 31, 1923. A. WOLFER.

NOTES

18. *Principal Magnetic Storms at the Cheltenham Magnetic Observatory, April to December, 1923.*[1]

Greenwich Mean Time		Range		
Beginning	Ending	Declination	Hor'l Int.	Vert'l Int.
h m	h m	′	γ	γ
Sept. 26, 20 —	Sept. 28, 3 —	66.8	161	157
Nov. 15, 22 —	Nov. 17, 9 —	51.1	173	112

19. *Principal Magnetic Storms Recorded at the Apia Observatory, January 1 to November 30, 1923.*[2]

Greenwich Mean Time		Range		
Beginning	Ending	Declination	Hor'l Int.	Vert'l Int.
1923 h m	h m	′	γ	γ
Feb. 25, 0 ..	Feb. 26, 12 ..	6.2	147	23
Mar. 24, 8 50	Mar. 25, 9 ..	4.7	114	16
Sept. 26, 23 ..	Sept. 27, 13 ..	4.3	130	18
Oct. 15, 3 ..	Oct. 17, 9 ..	5.0	100	Not recorded

The storm in October begins and ends very gradually, so that it is difficult to assign an exact hour in either of these times. Lat. 13°48.′4 S.; Long. 171°46′ or $11^h27.^m1$ W. of Greenwich.

20. *Alibag Observatory Magnetograms, 1906-1915.*—Dr. *S. K. Banerji*, Director of the Bombay and Alibag Observatories, Colaba, Bombay, India, has published recently two volumes of reproductions of selected magnetograms obtained at the Alibag Observatory for horizontal intensity during 1906 to 1914, vertical intensity during 1912 to 1915, and declination during 1912 to 1915. Because of instructions from his Government to observe the strictest economy, Dr. Banerji states that it is not possible, due to the considerable expenditure necessary for postage, to distribute these volumes to all of the institutions and magneticians to whom publications of the Observatory are usually sent. He states, however, that copies of these volumes, which weigh about six pounds, will be forwarded gladly, upon receipt of request with postage (Rs. 2 in Indian money), to any magnetician who may care to have them.

[1] Communicated by E. Lester Jones, Director, U. S. Coast and Geodetic Survey; Geo. Hartnell, Observer-in-Charge. Lat. 38° 44′.0 N.; Long. 76° 50′.5 or 5^h $07^m.4$ W. of Greenwich.

[2] Communicated by Andrew Thomson, acting director of the Apia Observatory; C. J. Westland, Observer.

21. *Magnetic and Allied Observations During Solar Eclipse, September 10, 1923.*—According to reports received especially from observers within or near the belt of totality appreciable magnetic and electric effects were experienced. The general magnetic conditions were ideal for the observance of eclipse effects; the publication of the reports will be begun in the next issue of the Journal.

22. *Magnetic Survey of Japan and Earthquake of September 1923.*—In a letter from Tokio dated October 24, 1923, Dr. *N. Watanabe* of the Central Bureau of Weights and Measures states that the catastrophe of September 1 did great harm to the official scientific work. Field notes of the magnetic survey of Japan of 1922 to 1923 were lost with the notes of the standardization of the magnetometers in the burning of the Hydrographic Office; this survey was completed at the end of August, when the party operating in the southern islands returned. Fortunately the abstracts of the observations at the stations were unharmed, and the computations of the survey will be made from these abstracts. While Dr. Watanabe's electric magnetometers were not damaged, the measuring apparatus and the laboratory where the electrical instruments were calibrated were burned. The chief scientific losses included the following: Destruction by fire of the Library of the Imperial University, Central Meteorological Observatory (excepting Library and Seismological Department), Hydrographic Office, National Electrical Laboratory, Bureau of Weights and Measures, and the Aero-Dynamical Laboratory. It appears that the building of the Science College of the Imperial University cannot be used again. Nine physicists and many of their assistants were lost in the Laboratory of the Tokio Electrical Company—makers of tungsten lamps amalgamated with the General Electric Company of America. Dr. Watanabe suffered no personal harm in the catastrophe, nor Professors *S. Nakamura* and *H. Nagaoka*. Prof. *A. Tanakadate* was in Europe at the time of the catastrophe.

23. *Central Meteorological Observatory of Japan and Kakioka Magnetic Observatory.*—Dr. *T. Okada* in a letter dated October 31, 1923 states that during the great fire which followed the tremendous earthquake of September 1, the *Central Meteorological Observatory* including the official residences of the staffs were burnt down; all of the books and periodicals were lost. The magnetographs for quick run registration, intended to be used in the solar-eclipse work of September 10 were destroyed. At *Kakioka*, the damage of the earthquake was very slight; a complete record of the three elements was taken. Dr. Okada narrowly escaped from being crushed by a tumbling safe in the clerk's room of the Central Observatory; the members of his family also escaped injury, but his dwelling and library were destroyed by the fire.

24. *Progress of the Maud Expedition.*—On December 3, 1923, a cablegram was received from Capt. *Amundsen* stating that according to news by wireless from the *Maud* the scientific work was progressing splendidly and that the position of the vessel was then 75°13′ North and 159° East of Greenwich. Captain Amundsen himself is at present in Norway completing arrangements for his transpolar flight from Spitzbergen in June 1924. He has been promised the aid of the United States Navy by the assignment of Lieut Ralph E. Davison to command one of the three airplanes to be used.

25. *MacMillan Arctic Expedition, 1923.*—Mr. R. H. Goddard of the Department of Terrestrial Magnetism is on duty with this expedition. According to information received by wireless a very satisfactory observatory has been built at the winter-quarters at Refuge Harbor, near Etah, Greenland and continuous registration of the magnetic elements and atmospheric potential-gradient are being obtained. The approximate values of the magnetic elements are: decl'n, 101° W; incl'n, 85°.8 N; hor'l int., 0.04 C. G. S.

26. *Resolutions on Terrestrial Magnetism, Pan-Pacific Science Congress, Australia, August-September 1923.*—The following resolutions pertaining to terrestrial magnetism were adopted:

"In view of the unique opportunity for international cooperation afforded by the geographical position of the Toolangi Magnetic Observatory, and of the scarcity of magnetic observatories in the Southern Hemisphere, this Congress strongly urges that adequate provision be made by the Government of Victoria for the prompt reduction of the observations and publication of the results."

"That this Congress desires to place on record its appreciation of the investigations, valuable both to geophysicists and navigators, that have been carried out on the non-magnetic survey yacht *Carnegie*, and expresses the hope that it will be possible to continue this work by the magnetic exploration of fresh ocean areas and by the determination of the secular variation of the magnetic elements."

"Understanding that the Imperial Government of Japan is considering the establishment of a geophysical and astronomical observatory on one of the Japanese mandatory islands in the Pacific, this Congress desires to express its belief in the scientific value of the scheme, and sincerely hopes that it may be carried out."

It was decided to hold the next meeting of the Congress in Japan in 1926.

27. *Utrecht Meeting of Commission for Terrestrial Magnetism and Atmospheric Electricity of the International Meteorological Committee, September 1923.*—At the Utrecht meeting of this Commission on September 6, 1923, the chief matters transacted were as follows:

It was considered desirable to continue the publication "Caractère magnétique de chaque jour," edited by the Royal Netherlands Meteorological Institute at De Bilt, and to insert in the quarterly tables a list of the five most disturbed days of each month (published hitherto once a year by the Institute on its own account).

It was agreed that in the list of calm days of the annual review of the "Caractère Magnétique" the mean character of the five days should be given; and that in the list of the most disturbed days the character-number of each of the five should be inserted.

The Meteorological Institute at De Bilt was asked to enter into correspondence with the directors of magnetic observatories, whose character-numbers are considerably different from the values assigned by the majority of the stations, in order to recommend them to choose a less diverging method of characterization.

It was thought advisable that problems like the "activity" of terrestrial magnetism should be left to the Section of Terrestrial Magnetism and Electricity of the International Geodetic and Geophysical Union; the Institute at De Bilt is willing to publish the results obtained by the Union in the publications concerning the "Caractère Magnétique."

The following resolutions were adopted:

1. That each country should provide for the regular intercomparison at intervals, not exceeding three years, of the magnetic instruments at all observatories within its bounds, and should designate some one of its own observatories as a place for intercomparisons with foreign instruments.

2. That the attention of directors should be called to the necessity for close critical examination of the methods employed in each observatory of determining the scale values of magnetic curves and the formulae employed, and for the publication of the results.

3. That each country investigating atmospheric electricity should have at least one observatory making systematic observations in atmospheric electricity (especially of potential gradient, earth-air current, conductivity and ionic charges) in such a way as to secure results strictly comparable amongst themselves and also comparable with analogous results obtained in other countries.

The Commission was continued for the present, Dr. Chree being elected *president*, and Prof. van Everdingen continuing as *secretary;* Prof. Adolf Schmidt was made a co-opted member.

28. *Transactions, Rome Meeting of Section of Terrestrial Magnetism and Electricity of the International Geodetic and Geophysical Union, 1922.*—These "Transactions," contained in an octavo volume of VIII + 182 pages, and edited by Louis A Bauer as secretary of the section and director of its central bureau, appeared in October as "Bulletin No. 3" from the Johns Hopkins Press of Baltimore. The typographical work was done by the Abingdon Press of Cincinnati. The volume contains the statutes and matters of organization of the International Research Council and the International Geodetic and Geophysical Union, reports on terrestrial magnetism and electricty from national and special committees and from certain investigators, minutes and resolutions of the Rome meeting, etc. One of the three plates shows the status of magnetic surveys in 1922; and another the distribution of magnetic observatories in 1922.

29. *United Kingdom National Committee of Geodesy and Geophysics.*—The sub-committee which is specially concerned with Terrestrial Magnetism and Electricity has been constituted as follows: The Astronomer Royal (Sir Frank Dyson), The Director Meteorological Office (Dr. G. C. Simpson), Professor S. Chapman, Dr. C. Chree (*Chairman*), Sir Arthur Schuster, Dr. A. C. Mitchell, Sir Napier Shaw and Mr. C. T. R. Wilson.

30. *International Geodetic and Geophysical Union, Madrid Meeting 1924.*—The dates for the next meeting of this Union, which will be at Madrid, have been tentatively set for October 1-10, 1924.

31. *Lectures in Geophysics.*—The following lectures are being given during the winter semester (1923-24) at the Sorbonne under the auspices of the Institut de Physique du Globe: Professor *Maurain*, General physical properties of the Globe and atmospheric electricity; M. *Dongier*, Physical properties of the atmosphere. Prof. *Edmond Rothé*, of the University of Strasbourg, will conduct, during May and June, 1924, a course in practical seismology with the object of training candidates for work at seismological stations.

32. *Personalia.*—We regret to record the following deaths: On December 6, 1923, at the age of 79 years, the Rev. *Marc Dechevrens*, S. J., director of the Zi-ka-wei Observatory in China, 1875-1887, and director of the Observatory St. Louis, Jersey, since 1894; Dr. *Fusakichi Omori*, the eminent seismologist, at Tokio on November 8, 1923; Dr. *Otto J. Klotz*, the well-known director of the Dominion Observatory at Ottawa, Canada, on December 28, 1923, at the age of 71 years.

The Rev. *Poisson*, S. J., has been appointed to succeed the late Rev. E. Colin as director of the Observatory of Tananarive. Among the medalists of the Royal Society at the anniversary meeting on November 30, 1923, were: Sir *William Napier Shaw* (Royal Medal), Professor *Horace Lamb* (Copley Medal), and Dr. *Robert Andrews Millikan* (Hughes Medal). Mr. *H. D. Harradon*, librarian of the Department of Terrestrial Magnetism, while on a furlough from October 1923 to August 1924, is pursuing special studies at Paris.

LIST OF RECENT PUBLICATIONS

A. Terrestrial and Cosmical Magnetism.

BATAVIA. Observations made at the Royal Magnetical and Meterorological Observatory at Batavia. Published by order of the government of Netherlands East-India by Dr. C. Braak, Director. Vol. 41, 1918. Batavia. Government Print. Office, 1923. (100 and 3 pls.) 36½ cm. P.

CHREE, C. Absolute daily range of magnetic declination at Kew Observatory, Richmond, 1858 to 1900. (Geophysical Memoirs, No. 22.) London, Meteorological Office, 1923 (47). 31 cm. P.

CHREE, C. Magnetic phenomena in the region of the South Magnetic Pole. London, Proc. R. Soc. Ser. A, Vol. 104, Sept. 1, 1923 (165-191 with 10 tables).

COIMBRA OBSERVATORY. Observações meteorológicas, magnéticas, e sísmicas feitas no Observatório Meteorlogico de Coímbra no ano de 1920. Volume LIX. Coimbra, Imprensa da Universidade, 1921 (xii + 200). 36 cm. P. [Contains magnetic observations, pages 139-178.]

HAZARD, D. L. Results of observations made at the United States Coast and Geodetic Survey Magnetic Observatory at Sitka Alaska, in 1919 and 1920. Washington, D. C., Dept. Comm., U. S. Coast Geod. Surv., 1923 (102 with 20 figs.). 23 cm.

HAZARD, D. L. Results of observations made at the United States Coast and Geodetic Survey Magnetic Observatory at Vieques, P. R., 1919 and 1920. Washington, D. C., Dept. Comm., U. S. Coast Geod. Surv., Serial No. 239. 1923 (100 with 10 pls.). 23 cm.

INDIA, METEOROLOGICAL DEPARTMENT. India weather review. Annual summary, 1920. (Contains solar and magnetic activity observations). Calcutta. Government Print. 1923 (26 and tables with 6 pls.). 30 cm. P.

INTERNATIONAL GEODETIC AND GEOPHYSICAL UNION. Transactions of the Rome Meeting, May, 1922. Section of Terrestrial Magnetism and Electricty. Edited by Louis A. Bauer, Secretary and Director of Central Bureau. Baltimore, Md. The Johns Hopkins Press. Bulletin No. 3. October, 1923. (181) 24 cm.

LUYKEN, K. Versuche und Messungen mit neuen Modellen des Bidlingmaierschen Doppelkompasses. Zs. angew. Geophysik, Berlin, Bd. 1, Heft 6, Oktober 1923 (161-182).

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PALAZZO, L. Rilevamenti magnetici nel versante medio e nelle minori isole del Tirreno. Estr. Roma, Rend. Acc. Naz. Lincei, v. 32, Ser. 5, 1° sem., 1923 (208-214).

PÉROT, A. Appareil pour la mesure rapide des éléments du champ magnétique terrestre. Soc. Franç. de phys., No. 179, 1922 (151-152). Rev., Physik. Ber., Braunschweig, 4. Jahrg., Heft 14, 1923 (818).

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ROHAN-CHABOT. Mesures magnétiques en Angola et en Rhodésia par la Mission Rohan-Chabot. Paris, C.-R. Acad. sci., T. 177, No. 8, Aug. 20, 1923 (458-460).

SCHERING, K., UND A. NIPPOLDT. Erdmagnetische Landesaufnahme von Hessen. Darmstadt, L. C. Wittich'sche Hofbuchdruckerei, 1923 (80 mit Karten u. Tafeln). 32 cm.

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TORONTO OBSERVATORY. Results of meteorological, magnetical and seismological observations, 1922. Published under the direction of Sir Frederic Stupart, F. R. S. C., Director of the Meteorological Service, Toronto. Toronto, Observatory Press, 1923 (ix+41). 20 cm.

TORTOSA, OBSERVATORIO DEL EBRO. Boletin mensual del Observatorio del Ebro. [v. 14, Nos. 1-3, Jan.-Mar., 1923.] Tortosa, Imprenta Moderna del Ebro de Algueró y Baiges, 1923, 32 cm. (Contains magnetic observations.)

UNITED STATES COAST AND GEODETIC SURVEY. Annual report of the Director, United States Coast and Geodetic Survey, to the Secretary of Commerce for the fiscal year ended June 30, 1923. Washington, D. C., Dept. Comm. U. S. Coast Geod. Surv., 1923 (149 with 38 maps). 23 cm. [Contains general account of the magnetic work of the U. S. Coast and Geodetic Survey during the fiscal year and sketches showing the magnetic stations occupied during the period in question.]

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Negro, C. Studi di elettricità atmosferica. II.—I collettori. Estr. Torino, Bol. Bimens. Soc. Meteor. Ital.; N. 4-6, Apr.—Giugno 1923, 4 pp.

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Power, A. D. The coefficient of recombination of the natural ions in air, and allied phenomena associated with weak atmospheric ionization. Philadelphia, Pa., J. Frank. Inst., v. 196, No. 3, Sept., 1923 (327-352).

NOTICE

Nos. 2 and 4 of Vol. I (April and October, 1896), and No. 1 of Vol. III (March, 1898), of the Journal *Terrestrial Magnetism and Atmospheric Electricity*, in response to numerous demands, have been reprinted. A few complete sets can still be supplied.

When possible to furnish without breaking a set, the price of single numbers of Vols. I, II and III is $1.50 for each, inclusive of postage, or $5.00 for the entire volume. Price of complete set, Vols. I to XXVII inclusive, with postage, $79.50.

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